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Essays on the International Transmission of Business Cycles

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Abstract

This dissertation studies different aspects of the transmission of international business cycles across countries. It consists of three chapters. In the first chapter, we study the role of trade in consumer durable goods and capital goods in the context of a two-country New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model. Our benchmark model, calibrated for the U.S. and its trading partners, is able to account for the high volatility and positive correlation of exports and imports observed in the data and discussed in the literature (Engel and Wang, 2011; Erceg, Guerrieri, and Gust, 2008). Moreover, it can also match the conventional interest rate channel that is a centerpiece of the NK framework. We compare our baseline model with alternative two-country NK models with and without consumer durable goods and capital goods. Our simulations show that our benchmark model performs better in the international dimension than the comparison models. In a version of the benchmark model with flexible prices, we found only a limited role of consumer durable goods. However, the presence of a nominal sector and price rigidities make consumer durable goods more important for the international dimension of the model. We also discuss plausible channels and shocks that can generate the observed dynamics in the trade variables. In addition to the total-factor-productivity channel discussed in the literature, we show that the interest rate channel together with incomplete pass-through of import prices can also generate positive correlation between export and imports. On the other hand, the investment channel emphasized in the literature may generate negatively correlated trade flows contrary to the observed correlation in the data.

In the second chapter, we study the impact of oil price fluctuations on oil-importing developing economies focusing on Armenia and Georgia as examples of small open economies. We explicitly model the world oil market and allow for fundamental oil shocks that originate from different sources such as oil supply disruptions or fluctuations in world economic activity (Kilian, 2009). We use a structural vector autoregressive model for this purpose. In parallel to the structural model, we also examine overall energy flows and plausible oil shock transmission mechanisms for the developing economies at hand. This is useful for understanding the specificities related to developing economies, selection of the relevant variables for the model, and interpretation of the results from the model. We document a number of interesting findings. First, based on the identified impulse responses, different types of oil shocks have different effects on key macroeconomic variables with the effect of oil supply shocks being quantitatively small. This is consistent with the findings for

developed economies. Thus, accounting for underlying reasons for increases in oil prices is important even for small open economies. Second, given that oil-market-specific demand shocks, which are considered important drivers of world oil prices, do not lead to higher inflation and in some cases even reduce the GDP, the demand channel can be an important transmission factor. Third, we find that real oil price jumps that stem from accelerating world economic activity have a positive effect on inflation (the effect is only marginally significant for Armenia). Given the high share of food items in the headline CPI of the developing economies under study and evidence that food prices are also driven by the dynamics in world economic activity (Baumeister and Kilian, 2013), this result suggests that part of oil price shocks can be transmitted through food prices. Finally, we find that the structure of energy flows and the pricing of natural gas matter for the transmission of oil shocks.

The topic of the third chapter is similar to that of the second chapter, but there are differences in methodology. This chapter analyses the impact of oil price fluctuations on oil-importing developing economies, focusing on Georgia as an example of a small open economy. Our objective is to understand the role of oil price jumps and the relevant transmission channels, given the specificities of developing economies. Following Kilian (2009), we explicitly model fundamental oil shocks in the international oil market and use a dynamic stochastic general equilibrium (DSGE) model with New Keynesian features to quantify the impact of oil price shocks and identify the key channels of transmission. We concentrate on the monetary policy channel, but also look at other transmission channels. A simple extension of a DSGE model allows us to account for limitations of monetary policy due to partial dollarization and credibility issues. The key parameters of the model, including those related to the monetary transmission channel and other energy shocks transmission channels, are estimated using Bayesian methods. Consistent with the evidence from developing countries, we find that macroeconomic variables and monetary policy respond to different types of oil shocks differently. The impact of oil supply shocks is quantitatively small, while oil price changes due to shifts in world economic activity and oil-market-specific demand have strong effects. Thus, we conclude that accounting for the original structural reason for changes in oil prices is important for understanding their impact even for small open economies. We also find that the role of the monetary policy channel in the transmission of oil price shocks is limited compared to developed economies, but is still quantitatively significant.

Abstrakt

Tato disertační práce zkoumá různé aspekty přenosu mezinárodních hospodářských cyklů mezi jednotlivými zeměmi. Skládá se ze tří kapitol. V první kapitole studujeme roli obchodu se spotřebním zbožím dlouhodobé spotřeby a kapitálovými statky v kontextu neokeynesiánského (NK) dynamického stochastického modelu všeobecné rovnováhy (DSGE) dvou zemí. Naším benchmarkem je model kalibrovaný pro USA a jejich obchodní partnery, který je schopen zohlednit vysokou volatilitu a pozitivní korelaci vývozů a dovozů pozorovanou v datech a diskutovanou v literatuře (Engel a Wang, 2011; Erceg, Guerrieri a Gust, 2008). Navíc také může zohlednit kanál všeobecných úrokových sazeb, který je ústředním bodem NK rámce. Porovnáváme náš výchozí model s alternativním NK modelem dvou zemí s a bez spotřebního zboží dlouhodobé spotřeby a kapitálových statků. Naše simulace ukazují, že náš benchmark model je lepší v mezinárodním rozměru než modely, se kterými ho srovnáváme. Ve verzi benchmark modelu s flexibilními cenami jsme nalezli pouze omezenou roli spotřebního zboží dlouhodobé spotřeby. Nicméně přítomnost nominálního sektoru a nepružnost cen dělají zboží dlouhodobé spotřeby důležitějším pro mezinárodní dimenzi modelu. Diskutujeme také možné kanály a šoky, které mohou generovat pozorovanou dynamiku obchodních proměnných. Ukazujeme, že kromě kanálu celkové produktivity výrobních faktorů diskutovaného v literatuře, také kanál úrokových sazeb spolu s neúplným promítáním dovozních cen může generovat pozitivní korelaci mezi vývozem a dovozem. Na druhou stranu investiční kanál zdůrazňovaný v literatuře může generovat negativně korelované obchodní toky v rozporu s pozorovanou korelací v datech.

Ve druhé kapitole studujeme dopad výkyvů cen ropy na rozvojové ekonomiky dovážející ropu se zaměřením na Arménii a Gruzii jako příklady malých otevřených ekonomik. Explicitně modelujeme světový trh s ropou a připouštíme fundamentální ropné šoky, které mají příčinu v různých jevech, jako jsou přerušení dodávek ropy nebo výkyvy světové hospodářské aktivity (Kilian, 2009). Pro tento účel využíváme strukturální vektorový autoregresní model. Souběžně se strukturálním modelem zkoumáme celkové energetické toky a možné přenosové mechanismy ropných šoků pro uvažované rozvojové ekonomiky. To je užitečné pro pochopení specifik týkajících se rozvojových ekonomik, výběru relevantních proměnných v modelu a interpretaci výsledků modelu. Dokumentujeme řadu zajímavých zjištění. Za prvé, na základě zjištěných impulsních odezev (impulse responses) různé typy ropných šoků mají různé efekty na klíčové makroekonomické veličiny, efekt ropných nabídkových šoků je kvantitativně malý. To je v souladu se zjištěními pro rozvinuté ekonomiky. Takže zohlednění základních důvodů pro růst cen ropy je důležité i pro malé otevřené ekonomiky. Za druhé, poptávkové šoky specifické pro ropný trh, které jsou považovány za důležité faktory ovlivňující světové ceny ropy, nemusí vést k vyšší inflaci a v některých případech dokonce snížit HDP, poptávkový kanál může představovat důležitý přenosový faktor. Za třetí, zjišťujeme, že skoky v reálných cenách ropy, které jsou způsobené zrychlující se světovou

ekonomickou aktivitou, mají pozitivní vliv na inflaci (efekt je jen marginálně významný pro Arménii). Vzhledem k vysokému podílu potravin v hlavních CPI u studovaných rozvojových ekonomik a vzhledem k důkazům, že ceny potravin jsou také poháněny dynamikou světové ekonomické aktivity (Baumeister a Kilian, 2013), tento výsledek naznačuje, že část ropných šoků může být přenesena prostřednictvím cen potravin. Dále jsme zjistili, že struktura dodávek energie a tvorby cen zemního plynu hrají roli při přenosu ropných šoků.

Téma třetí kapitoly je podobné tématu druhé kapitoly, ale jsou zde rozdíly v metodologii. Tato kapitola analyzuje dopad fluktuací ceny ropy na rozvojové ekonomiky dovážející ropu se zaměřením na Gruzii jako příkladu malé otevřené ekonomiky. Naším cílem je pochopit roli skoků v cenách ropy a příslušných přenosových kanálů s ohledem na specifika rozvojových ekonomik. Podobně jako Kilian (2009) explicitně modelujeme fundamentální ropné šoky na mezinárodním trhu s ropou a používáme model dynamické stochastické všeobecné rovnováhy (DSGE) s neokeynesiánskými vlastnostmi ke kvantifikaci dopadu šoků v ceně ropy a identifikaci klíčových přenosových kanálů. Soustředíme se zejména na kanál měnové politiky, ale také se zabýváme dalšími přenosovými kanály. Jednoduché rozšíření DSGE modelu nám umožňuje zohlednit omezení měnové politiky kvůli částečné dolarizaci a záležitostem spojených s důvěryhodností. Klíčové parametry modelu včetně těch, které souvisejí s měnovým přenosovým kanálem a dalšími přenosovými kanály šoků v energetice, jsou odhadnuty s využitím bayesovských metod. V souladu s důkazy z rozvinutých zemí zjišťujeme, že makroekonomické veličiny a měnová politika reagují na různé typy ropných šoků rozdílně. Dopad nabídkových ropných šoků je kvantitativně malý, zatímco změny ceny ropy v důsledku změn ve světové hospodářské aktivitě a v poptávce specifické pro trh s ropou mají silný dopad. Proto tedy usuzujeme, že zohlednění prvotního strukturálního důvodu změn cen ropy je důležité pro pochopení jejich dopadu v malých otevřených ekonomikách. Také zjišťujeme, že role kanálu měnové politiky v přenosu šoků v ceně ropy je omezená ve srovnání s rozvinutými ekonomikami, ale je stále ještě kvantitativně významná.

Introduction

The unifying theme of this dissertation is the transmission of business cycles across countries. The work is divided in two parts that examine two distinct areas of the process. The first chapter looks at the role of durable goods, including capital goods and durable consumption goods, in explaining characteristics of the business cycles of trade. Given that a large portion of imports and exports of developed industrialized economies consists of durable goods, the first chapter is relevant for this subset of the countries. The second part of the dissertation studies the impact of shocks in the international oil market, specifically focusing on small, open, oil-importing, developing economies. The second and the third chapters aim to understand how oil shocks are transmitted, what the differences between the developed and developing economies are in terms of the impact of shocks, and how we can explain these differences. Thus, the dissertation as a whole investigates the special characteristics of key trade components – durable goods and energy products, but given that these two components play different roles for developing and developed economies, the focus of each part of the dissertation is on different segments of the world economy.

Despite the large share of durable goods in the trade between developed economies, a standard modeling technique in open economy macroeconomics is to abstract this fact or allow it only a limited role. In non-microfounded models, economists would often render the imports component more volatile in order to make the model account for the dynamics of trade. Conventional open-economy dynamic stochastic general equilibrium (DSGE) models explicitly model capital goods, but their share in inter-country trade in the artificial economy is usually small. In chapter 1, we extend a standard open-economy New Keynesian model with durable consumption and capital goods and show that such an extension improves the ability of the model to match the data in the international dimension while maintaining its ability to account for the dynamics in the domestic dimension.

The second and the third chapters look at the impact of oil shocks on developing economies concentrating on the specificities related to the less developed institutions that characterize this group. We select Georgia and Armenia as examples of small, open, oil-importing, developing economies. Our objective is to understand the impact of oil shocks, the transmission mechanisms that explain the impact, and related differences between developing and developed countries. The two chapters tackle similar questions, but use alternative methodology to find answers.

We take a more data-oriented approach with a minimal structural model in the second chapter. We use a structural vector autoregressive (SVAR) model as our

main tool, but additionally we look at the dynamics of the data relevant to the transmission of oil shocks. It is well known that simple comovements in the data do not necessarily indicate causal impacts of interest. However, they help us to select the structure of the model and the relevant variables. We consider three aspects that are relevant for the transmission of oil shocks on developing economies. First, we allow the impact of oil price changes in small, open, developing economies to be different based on the fundamental shock in the international oil market that caused the change in the price. Second, we look at the impact of oil shocks in the context of overall energy flows. Finally, we analyze possible economic channels of transmission including monetary policy and demand channels.

The dynamics in raw data and the output of the SVAR model are useful for understanding the impact of oil shocks on key macroeconomic variables. However, this framework is not suitable for counterfactual analysis. For example, it is not possible to assess the role of monetary policy in the process of the transmission of oil price jumps through the economy. Thus, in the third chapter, we estimate a DSGE model adjusted for the specificities of the developing economies (Georgia in our case) to study in more detail how the oil shocks propagate. We look at different channels, but concentrate on monetary policy. We allow for limited impact of monetary policy due to partial dollarization and credibility issues.

Chapter 1

The Role of Trade in Consumer Durables and Capital Goods in a New Keynesian Framework

We study the role of trade in consumer durable goods and capital goods in the context of a two-country New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model. We find that such a model is able to account for the high volatility and positive correlation of exports and imports observed in the data and discussed in the literature (Engel and Wang, 2011; Erceg, Guerrieri, and Gust, 2008). Moreover, it can also match the conventional interest rate channel that is a centerpiece of the NK framework. We compare the performance of our baseline model with that of standard two-county NK models (Lubik and Schorfheide, 2006; Erceg et al., 2008) and find that our model performs better than the comparison model under baseline calibration. We also compare our baseline model with a version with capital goods only. Based on the comparisons, we can conclude that durable consumption goods improve the ability of the NK models to account for the dynamics of exports and imports. In a version of our benchmark model with flexible prices, we found only a limited role of consumer durable goods consistent with earlier findings of Baxter (1996). However, the presence of nominal sector and price rigidities make consumer durable goods more important for the international dimension of the model. In addition to the total-factor-productivity channel discussed in the literature, we show that the interest rate channel together with incomplete pass-through of import prices can also generate positive comovement between export and imports..

Keywords: New Keynesian models, Durable Goods, Business Cycles

JEL clasification: E32, E27, F44

1 Introduction

Dynamic stochastic general equilibrium (DSGE) models constitute an essential tool for macroeconomic analysis. Based on explicit microfoundations, such models create a powerful environment for formulating and formalizing relevant policy questions, conducting counterfactual experiments, and producing forecasts. The DSGE models in New Keynesian (NK) tradition, augmented with elaborate nominal side of the economy, are widely used by academicians to study monetary policy questions and by practitioners at central banks and related institutions as a guide to policy decisions and forecasting.

A standard textbook NK model (Woodford, 2003; Galí, 2009) is a simple and elegant framework that allows one to focus on interesting theoretical and policy issues while abstracting from the detailed structure of actual economies. Oftentimes, such an abstraction does not preclude researchers from accounting for interesting empirical regularities. For instance, the standard model does not explicitly incorporate investment decisions, but is rich enough to generate insights on various monetary and non-monetary phenomena such as the Taylor principle and the role of credibility in policy design. Nevertheless, investment and capital goods are available in more sophisticated, empirically-oriented closed-economy and open-economy NK models (Christiano, Eichenbaum, and Evans, 2005; Smets and Wouters, 2007; Bergin, 2006; Adolfson, Laséen, Lindé, and Villani, 2008). In an open economy context, standard NK models fail to capture the dynamics of key international trade variables. Detailed characteristics of exports and imports are usually not modeled explicitly in NK models, but this study shows that taking into account these characteristics helps us reconcile the predictions of a NK model with the regularities observed in the data.

The purpose of this paper is to simultaneously incorporate capital goods and durable consumption goods into an open-economy NK setup, analyze the properties of the model, and show that the extended model is able to match key business cycle characteristics for real and nominal sides of the hypothetical economy better than an NK model of similar level of complexity without durable goods.[1] In particular, under our baseline calibration the model is able to replicate the dynamics of the trade variables consistent with the findings of Engel and Wang (2011) (EW henceforth). Moreover, the responses of the model variables to a monetary policy shock qualitatively match the impulse responses identified in empirical literature (Chris-

[1]The durable goods category encompasses durable consumption goods and capital (or investment) goods. In the closed economy setup some authors include private residential investment either in durable consumption or in private investment. However, since the focus of this study is on the trade in durables, we abstract residential sector as it can be considered as nontradable and arguably its behavior is distinct from other categories.

tiano, Eichenbaum, and Evans, 1999; Barsky, House, and Kimball, 2003; Erceg and Levin, 2006).

This study is motivated by a number of empirical observations and theoretical findings which indicate that durable consumption and durable trade make up an important channel that may help us understand the dynamics of macroeconomic variables in an open economy context with significant implications for monetary policy design.

Domestic production and cross-country trade exhibit striking dissimilarity in terms of their composition. It is well known that for most developed and developing countries, durable consumption expenditures and gross private domestic investment expenditures account for a relatively modest portion of aggregate production. For instance, according to the U.S. Bureau of Economic Analysis, they constituted respectively 8.1% and 17% of the U.S. GDP in U.S on average in 2000-2012. In contrast, as documented by EW, capital goods and durable consumption goods constitute the lion's share of international trade between developed countries. They argue that explicitly incorporating durable goods (consisting of capital goods and durable consumption goods) into the modeling framework is eppirically realistic because for a sample of 25 OECD countries (for 2000) durable goods constitute on average 68% of imports and 64% of exports, excluding the energy products. Their statistics indicate that these shares are rather stable and uniform across developed economies. For example, the share of durables is 69% of imports and 75% of exports for the U.S.A. and 72% and 75% for the Czech Republic.

Further, EW report that at the business cycle frequencies real imports and exports are procyclical, much more volatile than output, and correlate positively with one another (these findings are labeled "trade volatility" and "positive comovement"). Their statistics indicate that the high volatility of trade variables is rather robust across developed countries, and the positive correlation holds for the vast majority. On average the standard deviations of real imports and exports exceed that of output by 3.25 and 2.73 across the sample of 25 OECD countries.

EW state that the standard international RBC models and DSGE models in general are not able to replicate the trade dynamics discussed above as these models generate import and export volatilities that are much lower than the volatilities observed in the data. They argue that in standard one-sector models, the source of the volatility of imports is either the volatility of demand for the final goods or the substitution between home-produced and imported goods.[2] The first channel is not strong enough in conventional one-sector models to generate high volatility of imports because a large share of imported goods goes to consumption, which is

[2]Similar logic applies to exports because in a two-country setting, exports from one country are imports in another.

even less volatile than the output. On the other hand, increasing the variation in imports utilizing the substitution channel, leads to negatively correlated exports and imports. EW demonstrate that if one artificially induces fluctuations in exchange rate (through, for instance, uncovered interest parity shock), the trade variables do grow more volatile as the substitution effect between imports and exports becomes stronger, but they also become negatively correlated, in contrast to the positive comovement observed in the data.

Once durable consumption goods are introduced, an additional source of variation becomes available. EW develop a two-country RBC model that features an extra sector that manufactures durable goods. These goods, used either for durable consumption or as capital goods, are traded between the countries, while the nondurable goods are assumed to be nontradable. Simulations under the standard calibration show that it is possible to replicate trade volatility and positive comovement along with other standard model characteristics in the literature. However, the results of the model seem to depend on the share of durable goods in output (the share of durable goods is calibrated to 40% of GDP) and the absence of nondurables in international trade. Erceg et al. (2008) discuss the same mechanism in a two-country NK model concentrating on the trade in investment goods and abstracting from durable consumption goods. They also find that the presence of traded capital goods and their realistic share of cross-coutry trade improves the ability of the model to replicate the dynamics of the trade variables.

In general, from a modeling perspective, durable consumption and durable trade may induce different transmission mechanisms in NK context compared to IRBC settings. First, most importantly the NK framework includes elaborate nominal side with frictions in price-setting (and wage-setting) behavior. This implies that the reaction of key prices will be smoother and probably quantitatively smaller, inducing different reaction of the real variables. Second, non-trivial nominal sector makes monetary policy a relevant factor that may alter the transmission mechanism compared to a case with the flexible prices. Thus, policy decisions related to differential sectoral responses and exchange rate responses may matter for the dynamics of the trade variables. Finally, additional shocks (including the monetary policy shock) drive fluctuations in the NK setup, and the behavior of the trade variables may be rather different under additional types of shocks.

The key driver of aggregate fluctuation in an IRBC framework is the variation in total factor productivity (TFP). In a model with nondurable and durable goods sectors, a temporary positive shock to the TFP process in the durables sector makes the sector more productive and the home-produced durable goods cheaper.[3] The terms of trade (defined as the price of imports divided by the price of exports)

[3]Transmission mechanism is similar for the TFP shock in nondurables sector.

increase (deteriorate). The income effect pushes the demand for imported goods up, while the substitution effect stimulates cheaper domestically-produced durables and their exports. Some of the domestic demand for the imports is diverted to less expensive domestic goods, but in the baseline model considered by EW the income effect dominates. Thus, both imports and exports move in the same direction. High price sensitivity of durable consumption and investment goods results in volatile trade variables.

Now consider a monetary policy shock in the open-economy NK framework: A positive shock to the nominal interest rate – a tightening of monetary policy – leads to temporarily rising real interest rate, depressed demand, decelerating inflation, and currency appreciation in the short term. Traded goods are durable and very sensitive to price changes, and even relatively modest price differences may trigger large adjustments in imports and exports. Though the terms of trade improve after the policy tightening (making the imported goods less expensive), depressed aggregate demand acts as a counterweight, i.e., imports are negatively affected by the income effect, but the substitution effect pushes them in the other direction. On the other hand, exports decrease as they become more expensive due to currency appreciation (given that domestic economic contraction does not fully transmit to the foreign country or the world economy). Thus, a shock to monetary policy may induce both negative and positive correlation between exports and imports.

It is not a priori clear whether the trade in durables mechanism suggested by EW will improve the ability of an NK model to account for the joint dynamics of the trade variables, especially in terms of matching their positive comovement, highlighted by the authors. As mentioned, the role of monetary policy is of interest as well. Thus, we extend the standard NK model by augmenting it with the production and trade in durable consumption (and investment) goods; we concentrate on the "standard" features of the NK model but emphasize the dynamics of the traded sector. The next section is a review of the relevant literature.

The remainder of the chapter is organized as follows. Section 3 describes our two-country model with nondurable and durable sectors and sticky nominal prices that is used for simulations. Section 4 presents the simulation results from the benchmark calibrated model and compares them to the simulation results from alternative standard NK models. Section 5 concludes the discussion.

2 Literature Review

Baxter (1996) studies the role of durable consumption and investment goods for the transmission of business cycles in an otherwise standard two-sector closed-economy

RBC setting.[4] The author reports a number of interesting findings. First, she finds that the model driven by the estimated TFP process is consistent with the standard facts of the business cycles. She is also able to match the cross-sectoral comovements that are otherwise difficult to account for. Second, about half of the measured volatility of durable goods sector is due to the endogenous propagation mechanism while the other half may be attributed to the higher volatility of the shocks. Finally, Baxter (1996) found little evidence that durable consumption goods *per se* are a quantitatively important propagation mechanism since the depreciation rate parameter for this variable had little effect on the dynamics of the model economy.

Barsky et al. (2007) incorporate durable consumption into a standard closed-economy NK framework and compare the results to a baseline case with no durability feature. They introduce an additional sector that produces durable goods in parallel to the conventional nondurable sector. Their model does not include capital goods, but Barsky et al. (2007) argue that their main results are also applicable to a case with capital goods but without durable consumption goods. The setup at the sectoral level is a standard one often found in NK models. We may think of each sector as consisting of two layers of firms. The first layer contains a set of intermediate firms that produce intermediate goods via the constant-returns-to-scale technology. Each intermediate firm enjoys a degree of monopoly power but is constrained in setting the price for their product in the Calvo-Yun manner. In the second layer, the intermediate goods are aggregated into a final good by a competitive aggregator firm.[5] The households derive utility from consumption of nondurable goods and maintain a stock of durable goods that depreciates at a constant rate every period and provides the flow of services. The monetary sector is modeled as exogenously given stationary money growth process (money supply follows a random walk) with money demand postulated to be proportional to nominal GDP.[6]

The authors demonstrate that the presence of durable consumption goods substantially changes the qualitative (and respectively quantitative) response of the model variables to a monetary policy innovation with results depending on the degree of price stickiness in the durable sector. For the standard values of the parameters, the model behaves similarly to a conventional NK model with no durable consumption goods only if the prices in the durable sector are sticky. In case of flexible price-setting in the durable sector, the monetary policy is near neutral even if there is substantial nominal rigidity in the nondurable sector, despite the fact that the share of nondurable consumption goods in aggregate GDP is set at only 25% in the steady state. Moreover, when the prices of durable goods are flexible,

[4]The model is calibrated so that durable goods include residential housing.

[5]This is also the structure used in our benchmark two-country model.

[6]Our replication of the model from Barsky et al. (2007) shows that their results also hold under a Taylor-type monetary policy reaction function.

their production decreases substantially in response to expansionary monetary policy shock neutralizing the increased production in the nondurable sector. This is counterfactual to empirical findings that both durable and nondurable consumption increase after such a shock (Barsky et al., 2003; Erceg and Levin, 2006; Monacelli, 2009). From theoretical point of view, durable goods and the level of price stickiness in the durable sector significantly influence the behavior of aggregate consumption and other aggregate variables in terms of their responses to monetary policy shocks despite their low share in the economy. These goods constitute an endogenous mechanism that delivers insights into the behavior of aggregate consumption as well as sector-specific variables, which may be interesting for policy design on their own.

Barsky et al. (2007) argue that the driving factor behind these results is the near-constancy of the shadow value of durable goods with low depreciation rate. The shadow value is defined as the expected discounted sum of marginal utility flows from the stock of durable goods. Given the low depreciation rate of durable goods, the flow-to-stock ratio of durables is rather low, and even relatively large changes in current production may not significantly alter the overall stock. Furthermore, the flow of services in the distant future may have significant impact on the shadow value, and consumers have relative freedom to shift the flows through time. Thus, the elasticity of intertemporal substitution is rather high, and even minor shifts in relative prices may generate substantial swings in consumption of durable goods.

Erceg and Levin (2006) study optimal monetary policy design in a model with durable consumption goods. The setup is similar to Barsky et al. (2007) but also includes nominal rigidities in wage-setting with immobile labor across the durable and nondurable sectors. Additionally, their model features fixed duration Taylor type price-setting rather than Calvo-Yun type pricing and the utility function is separable in its components to facilitate welfare analysis. The authors note that the presence of an additional sector is a challenge for the central bank as it has to stabilize the output gaps in two sectors with a single instrument because there is a trade-off between the stabilization objectives across the sectors. First, they show that households' welfare depends on the variance of sectoral output gaps (up to second-order approximation), and the dispersion of prices and wages in each sector. Second, Erceg and Levin (2006) analyze the performance of different policy rules with welfare loss relative to flexible price (and wage) equilibrium used as metric. They find that even for an optimal monetary policy reaction under commitment there is a welfare loss of about 4% of steady-state output level as there is a trade-off in stabilizing output gaps in the two sectors. Under such a policy, the durable sector output reacts more sharply to shocks to the economy, the output gap is relatively more volatile, and a higher portion of welfare loss originates in the durable sector. Furthermore, their study argues that simpler rules targeting weighted aggregates

of sectoral variables perform well compared to the optimal rule. The bottom line is that even though the monetary authority may not need to respond to the sector specific variables (as the rules designed to react to weighted aggregates perform well), the specificities of the durable sector changes the behavior of aggregate variables significantly compared to the standard NK setup.

We have already discussed EW, who, similarly to Baxter (1996), also studies the role of durable consumption and investment goods in an RBC context, but from an open-economy perspective. Erceg et al. (2008) examine a similar idea in a two-country two-sector NK model. They do not explicitly model durable consumption goods and investment goods simultaneously, but allow the imports to contain an empirically realistic share of durable goods. The DGSE model used is an extension of the Federal Reserve's SIGMA model described in Erceg et al. (2005). The model has an elaborate nominal side with wage and price rigidities and monetary policy. Compared to EW, the real side of the model economy in Erceg et al. (2008) additionally features costs to adjusting imported inputs in production, habit persistence in nondurable consumption, non-Ricardian households, and an elaborate government sector.

Erceg et al. (2008) compare two alternative specifications: absorption-based trade specification (AT) and disaggregated trade specification (DT). The latter stipulates separate behavioral equations for trade in non-durable consumer goods and for trade in investment goods. The underlying technologies are also allowed to differ across the durable and nondurable sectors with the production of investment goods being more import-intensive. They argue that DT specification matches the evolution of trade series better. Moreover, given the high share of investment goods in the DT specification investment shocks may play an important role in explaining the dynamics of trade, while the role of relative prices may be limited. The code for replication of the model is available from Wieland, Cwik, Müller, Schmidt, and Wolters (2012), and we use it as one of the benchmark comparison models.

Thus, the durable sector plays a key role in explaining the dynamics of macroeconomic variables in at least two distinct dimensions. On the one hand, the compositional differences in trade and national aggregates appropriately modeled in an open-economy DSGE model enable it to match the volatility and positive comovement of the trade variables. On the other hand, the distinctive response of durable goods to monetary policy shocks make them a significant channel in the NK framework with interesting theoretical and policy implications. Bringing the two dimensions together into a unified open economy NK environment would allow simultaneous analysis of these two important facets of the business cycle dynamics that are often ignored in conventional NK models. Moreover, in an open-economy setting, the literature usually does not analyze durable consumption goods and cap-

ital goods separately. For instance, EW only discuss the joint implications of these two categories. They do compare their results to what they refer to as a standard NK model, but the latter model does not allow for international trade in capital goods. Erceg et al. (2008) allow for the trade in capital goods but do not explicitly model durable consumption goods. Therefore, we are interested in whether the consumer durables are instrumental in improving the performance of the NK model.

3 Model

A two-country two-sector model utilizes the real economy structure found in the baseline model of EW but also incorporates NK features such as monopolistic competition and price rigidities. As noted earlier, a similar setup of the durable sector may be found in Barsky et al. (2007) and Erceg and Levin (2006). A New Keynesian two-country model without durable consumption goods and capital goods was developed by Lubik and Schorfheide (2006). Erceg et al. (2008) developed a two-country model with traded capital goods.

The world economy is populated by symmetric "home" and "foreign" countries. (Figure 1.1 below summarizes the structure of the economy from the home country perspective; symmetric structure applies to the foreign economy). The home economy is calibrated to match the characteristics of the US economy, while the foreign country represents the rest of the world. A typical economy consists of a large number of households and two production sectors that manufacture nondurable and durable goods. The durable goods may be used for investment in durable consumption stocks and capital stocks. Nondurable goods are not traded.

We use the following notation to describe the model. Subscripts indicate the country of final use ($\{H, F\}$) and time index, where H stands for Home and F for Foreign. Superscripts designate the sector that the variable is associated with ($\{N, D\}$) and the country of origin ($\{H, F\}$). N is Nondurable and D is Durable. For example, variable X_{Ht}^{DH} is a (dummy) variable that is ultimately used in the home country and is related to the durables sector of the home country.

Consumers

The households choose infinite streams of nondurable consumption and durable consumption services, decide on the amount of labor hours to supply, and maintain stocks of capital used in each of the production sectors.

We experimented with two types of asset markets. In one specification, we assumed that the financial markets are complete across the countries, allowing them to hedge country-specific risks. In an alternative specification, we assumed that the

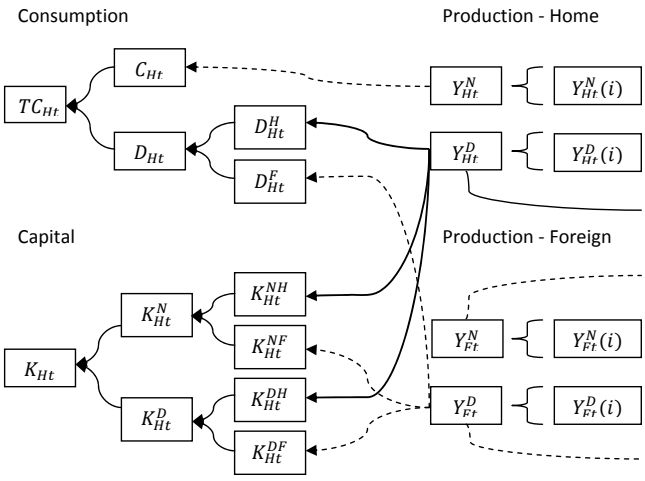

Figure 1.1: Model Structure: TC_H – total consumption of home economy residents, C_H – nondurable consumption, D_H – durable consumption stock, D_H^H – durable consumption stock produced at home, D_H^F – durable consumption stock produced abroad, K_H – capital stock maintained by home country residents, K_H^N – capital stock used in nondurable sector, K_H^D – capital stock used in durable sector, $K_H^{NH}(K_H^{NF})$ – capital stock used in nondurable sector originally produced at home (abroad), $K_H^{DH}(K_H^{DF})$ – capital stock used in durable sector originally produced at home (abroad), Y_H^N – final nondurable goods produced at home, $Y_H^N(i)$ – intermediate goods used for the production of Y_H^N, Y_H^D – final durable goods produced at home, Y_F^N, Y_F^D – final nondurable and durable goods produced abroad. Note: nondurable goods are not traded.

financial markets are complete within the countries and only non-contingent real bonds are available for trade across the countries. In the first case, complete international asset markets are implemented through nominal state-contingent bonds denominated in home-country currency and accessible to the agents in both countries. For instance, a consumer in a home country may pay $Q_{t,t+1}B_{H,t+1}$ USD in period t to obtain $B_{H,t+1}$ USD in a particular state in period $t+1$. $Q_{t,t+1}$ is the state-contingent discount factor for a unit of nominal currency unit in a particular state next period, and $B_{H,t+1}$ are the nominal bonds held by consumers in the home country. Similarly, a consumer in the foreign country has to pay $Q_{t,t+1}S_tB_{F,t+1}$ USD to get $\frac{S_t}{S_{t+1}}B_{F,t+1}$ USD in a specific state a period after.[7] S_t is the home-country currency exchange rate per unit of foreign currency. Given that the results are similar for both specifications, we report only those with complete international financial markets.

The agents take the price of the final nondurable and durable consumption, the wage rate, real interest rate on bonds, return for each type of capital, and profits paid by the firms as given. Changing the stocks of durable consumption goods and capital goods is subject to adjustment costs. The preference structure in terms of functional forms and nesting of goods is identical to that used in the baseline IRBC model of EW. The budget constraint is modified to accommodate the inclusion of

[7]The variables depend on the particular state of the economy, but we do not use this notation explicitly for simplicity.

the profits not present in the baseline setup with perfect competition.

$$\begin{aligned} P^N_{Ht}C_{Ht} + P^{DH}_{Ht}(d^H_{Ht} + \Delta^H_{Ht} + I^{NH}_{Ht} + \Lambda^{NH}_{Ht} + I^{DH}_{Ht} + \Lambda^{DH}_{Ht}) + E_t(Q_{t,t+1}B_{H,t+1}) + \\ P^{DF}_{Ht}(d^F_{Ht} + \Delta^F_{Ht} + I^{NF}_{Ht} + \Lambda^{NF}_{Ht} + I^{DF}_{Ht} + \Lambda^{DF}_{Ht}) \leq \\ W_{Ht}L_{Ht} + B_{Ht} + R^{NH}_{Ht}K^{NH}_{Ht} + R^{NF}_{Ht}K^{NF}_{Ht} + R^{DH}_{Ht}K^{DH}_{Ht} + R^{DF}_{Ht}K^{DF}_{Ht} + \Omega_{Ht}. \end{aligned} \tag{1.1}$$

P^{JK}_{Ht} is a price of finished products (durable or nondurable goods produced at home or abroad) in equation (1.1) above. W_{Ht} is the wage rate; since the labor is mobile across the sectors, the wage is uniform across the sectors. R^{JK}_{Ht} is the rental rate on capital for each type of capital. The households effectively maintain four stocks of capital based on where it is used (nondurable and durable sectors) and where it was originally produced (home or foreign economies). There is substitutability between capital types within sectors but no movement across the sectors. d^K_{Ht} is the investment in durable consumption goods produced in country K, and I^{JK}_{Ht} is the investment in sector J capital produced in country K. Δ and Λ stand for respective adjustment costs for durable consumption and investment goods. Finally, Ω_{Ht} is the sum of the dividends received from the intermediate firms in both sectors.

Every period the stocks of the durable consumption goods and capital depreciate at fixed rates of δ_D and δ respectively. Their laws of motion are given below.

$$D^{\tilde{K}}_{H,t+1} = (1-\delta_D)D^{\tilde{K}}_{Ht} + d^{\tilde{K}}_{Ht} \tag{1.2}$$

$$K^{J\tilde{K}}_{H,t+1} = (1-\delta)K^{J\tilde{K}}_{Ht} + I^{J\tilde{K}}_{Ht} \tag{1.3}$$

Firms

The nondurable and durable production sectors consist of a large number of the final goods producers and intermediate goods producers.

The final goods producers are perfectly competitive. They aggregate the intermediate goods into the final product according to the following standard production function ($J = \{N, D\}$ stands for the sector).

$$Y^J_{Ht} = \left(\int_0^1 (Y^J_{Ht}(i))^{\frac{e-1}{e}} di \right)^{\frac{e}{e-1}}. \tag{1.4}$$

The inputs – $Y^J_{Ht}(i)$ are supplied by the intermediate firms distributed on the unit interval. The parameter e is the elasticity of substitution. The higher the elasticity, the less the monopolistic power of the intermediate firms.

Cost minimization and perfect competition among the final goods producers leads to the following two expressions of the demand for intermediate goods and final price.

$$Y_{Ht}^J(i) = \left(\frac{P_{Ht}^{JH}(i)}{P_{Ht}^{JH}}\right)^{-e} Y_{Ht}^J, \tag{1.5}$$

$$P_{Ht}^{JH} = \left(\int_0^1 (P_{Ht}^{JH}(i))^{1-e} di\right)^{\frac{1}{1-e}}. \tag{1.6}$$

The intermediate goods producers rent capital and hire labor to produce the intermediate goods. The technology process (A_{Ht}^J) is exogenous and subject to random fluctuations.

$$Y_{Ht}^J(i) = A_{Ht}^J (K_{Ht}^J(i))^{\chi} (L_{Ht}^J(i))^{1-\chi}. \tag{1.7}$$

The capital used in production is a composite of home-produced and foreign-produced capital types.

$$K_{Ht}^J = \left(\alpha^{\frac{1}{\gamma}} (K_{Ht}^{JH})^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}} (K_{Ht}^{JF})^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}. \tag{1.8}$$

We may think of intermediaries minimizing the costs given the rent for each type. This would give us the demand for each capital type given the respective interest and composite capital. If the market for the intermediaries is competitive, the marginal cost would be the rental rate for the composite capital.

$$K_{Ht}^{JH} = \alpha \left(\frac{R_{Ht}^{JH}}{R_{Ht}^J}\right)^{-\gamma} K_{Ht}^J, \tag{1.9}$$

$$K_{Ht}^{JF} = (1-\alpha) \left(\frac{R_{Ht}^{JF}}{R_{Ht}^J}\right)^{-\gamma} K_{Ht}^J, \tag{1.10}$$

$$R_{Ht}^J = \left(\alpha (R_{Ht}^{JH})^{1-\gamma} + (1-\alpha)(R_{Ht}^{JF})^{1-\gamma}\right)^{\frac{1}{1-\gamma}}. \tag{1.11}$$

If we go back to intermediate firms, their behavior is described as a two-step process. First, given the rental rate on composite capital, the wage rate, and the level of output, they minimize the costs. Second, they set the price on their product given the demand and the constraint on price adjustment. The cost minimization yields the following demand functions for the inputs.

$$K^J_{Ht}(i) = \chi MC^J_{Ht}\frac{Y^J_{Ht}(i)}{R^J_{Ht}}, \tag{1.12}$$

$$L^J_{Ht}(i) = (1-\chi)MC^J_{Ht}\frac{Y^J_{Ht}(i)}{W_{Ht}}, \tag{1.13}$$

$$MC^J_{Ht} = (A^J_{Ht})^{-1}\chi^{-\chi}(1-\chi)^{\chi-1}(R^J_{Ht})^{\chi}W^{1-\chi}_{Ht}. \tag{1.14}$$

The prices are set to maximize discounted expected sum of future profits. Every period only a fraction $(1-\mu_J)$ of the firms is able to set the price optimally. The rest keep the price from the previous period. The objective function could be written as follows.

$$\Omega^J_{Ht}(i) = E_t\sum_{k=0}^{\infty}\mu^k_J Q_{t,t+k}\left(P^{JH}_{Ht}(i) - MC^J_{H,t+k}\right)\left(\frac{P^{JH}_{Ht}(i)}{P^{JH}_{H,t+k}}\right)^{-e}Y^J_{H,t+k}. \tag{1.15}$$

Given that the consumers are the ultimate owners of the intermediate firms, the firms discount expected profits using the stochastic discount factor from consumers' optimization problem: $Q_{t,t+k} = \beta^k\frac{\lambda_{H,t+k}}{\lambda_{Ht}}\frac{P^N_{Ht}}{P^N_{H,t+k}}$, where λ_{Ht} is the marginal utility of nondurable consumption, and P^N_{Ht} is price of a unit of nondurable good. The firms maximize the expected discounted profit $(\Omega^J_{Ht}(i))$ by choosing the price for the intermediate good $(P^J_{Ht}(i))$ taking into consideration that they may not be able to set the optimal price in the future with a given probability (μ_J).

The first order condition with respect to the price set by a specific firm i may be written as follows.

$$\frac{P^{JH}_{Ht}(i)^\star}{P^{JH}_{H,t-1}}E_t\sum_{k=1}^{\infty}Q_{t,t+k}\mu^k_J(\Pi^{JH}_{Ht}\cdots\Pi^{JH}_{H,t+k})^e Y^J_{H,t+k} =$$
$$\frac{e}{e-1}E_t\sum_{k=1}^{\infty}Q_{t,t+k}\mu^k_J(\Pi^{JH}_{Ht}\cdots\Pi^{JH}_{H,t+k})^{1+e}Y^J_{H,t+k}\frac{MC^J_{H,t+k}}{P^{JH}_{H,t+k}}. \tag{1.16}$$

We may split this equation into the equations written in recursive form:

$$\frac{P^{JH}_{Ht}(i)^\star}{P^{JH}_{H,t-1}}X1^J_{Ht} = \frac{e}{e-1}X2^J_{Ht}, \tag{1.17}$$

$$X1^J_{Ht} = \frac{(\Pi^{JH}_{Ht})^e}{\Pi^N_{Ht}}\left(Y^J_{Ht}\lambda_{Ht} + \mu_J\beta E_t(X1^J_{H,t+1})\right) \tag{1.18}$$

$$X2^J_{Ht} = \frac{(\Pi^{JH}_{Ht})^{1+e}}{\Pi^N_{Ht}}\left(Y^J_{Ht}\lambda_{Ht}\frac{MC^J_{Ht}}{P^{JH}_{Ht}} + \mu_J\beta E_t(X2^J_{H,t+1})\right) \tag{1.19}$$

The equation for aggregate price and the Calvo type price-setting constraints imply the following relation between the optimal price (which is the same among the firms that adjust the price) and gross inflation.

$$\frac{P_{Ht}^{JH}(i)^{\star}}{P_{H,t-1}^{JH}} = \left(\frac{(\Pi_{Ht}^{JH})^{1-e} - \mu_J}{1-\mu_J} \right)^{\frac{1}{1-e}}. \tag{1.20}$$

Equations (1.17) to (1.20) represent the New Keynesian Phillips curve written in nonlinear form.

Note that some of the equations still depend on firm specific index i, and we need to write them in terms of aggregate variables rather then specific variables related to particular firms on the unit interval. We can easily aggregate the factor demands by the individual intermediate firms.

$$K_{Ht}^{J} = \chi MC_{Ht}^{J} \frac{Y_{Ht}^{J}}{R_{Ht}^{J}} \int_0^1 \left(\frac{P_{Ht}^{JH}(i)}{P_{Ht}^{JH}} \right)^{-e} di = \chi MC_{Ht}^{J} \frac{Y_{Ht}^{J}}{R_{Ht}^{J}} \mathscr{P}_{Ht}^{JH}, \tag{1.21}$$

$$L_{Ht}^{J} = (1-\chi) MC_{Ht}^{J} \frac{Y_{Ht}^{J}(i)}{W_{Ht}} \int_0^1 \left(\frac{P_{Ht}^{JH}(i)}{P_{Ht}^{JH}} \right)^{-e} di = (1-\chi) MC_{Ht}^{J} \frac{Y_{Ht}^{J}}{W_{Ht}} \mathscr{P}_{Ht}^{JH}. \tag{1.22}$$

$\mathscr{P}_{Ht}^{JH}$ is a price dispersion that can be shown to obey the following equation:[8]

$$\mathscr{P}_{Ht}^{JH} = (\Pi_{Ht}^{JH})^{e} \left((1-\mu_J)(P_{Ht}^{JH\star}(i))^{-e} + \mu_J \mathscr{P}_{H,t-1}^{JH} \right). \tag{1.23}$$

Foreign intermediate durable goods are subject to local-currency pricing (non-durable goods are not traded across countries). This is implemented through domestic importers that repackage foreign intermediate goods and sell them to a perfectly competitive domestic import aggregator firm. The latter directly supplies the aggregate imported good to domestic consumers.

The problem of the importer firms is similar to that of the intermediate domestic producers. They are subject to monopolistic competition and Calvo-type price setting constraints. Their objective function for the price setting decision may be written as follows:

$$\Omega_{Ht}^{M}(i) = E_t \sum_{k=0}^{\infty} \mu_M^k Q_{t,t+k} \left(P_{Ht}^{DF}(i) - \frac{S_t P_{Ft}^{DF}}{(1-\tau)} \right) \left(\frac{P_{Ht}^{DF}(i)}{P_{H,t+k}^{DF}} \right)^{-e} M_{H,t+k}, \tag{1.24}$$

where M_{Ht} is the aggregate imports consisting of the investment in consumer durables

[8]The derivations may be found in Schmitt-Grohé and Uribe (2007).

and capital goods.

Other Conditions

The market clearing conditions are identical to those found in the baseline paper. In particular, the labor market and the markets for nondurable and durable consumption goods clear. The optimal portfolio of international assets satisfies the following first-order conditions for the home and foreign countries.

$$Q_{t,t+1} = \beta \frac{\lambda_{H,t+1}}{\lambda_{Ht}} \frac{1}{\Pi^N_{Ht}} \tag{1.25}$$

$$Q_{t,t+1} = \beta \frac{\lambda_{F,t+1}}{\lambda_{Ft}} \frac{1}{\Pi^N_{Ft}} \frac{S_t}{S_{t+1}} \tag{1.26}$$

Given the above conditions, absence of arbitrage implies that the home and foreign marginal utilities (λ_{Ht} and λ_{Ft}) are related according to the following equation.[9]

$$\frac{\lambda_{Ft}}{\lambda_{Ht}} = \frac{S_t P^N_{Ft}}{P^N_{Ht}} \tag{1.27}$$

An asset that delivers one unit of home country currency (USD) in every state the next period is priced at $\frac{1}{1+i_{Ht}} = E_t(Q_{t,t+1})$. This is the nominal interest rate set by the central bank of the home country. Similarly, a unit of foreign currency in any particular state next period may be discounted by the foreign consumers by $\frac{1}{1+i_{Ft}} = E_t(Q_{t,t+1}\frac{S_{t+1}}{S_t})$. Foreign nominal interest rate is appropriately set by the foreign monetary authority.

The monetary policy reaction is modeled as a type of Taylor rule where the nominal short-term interest rate in a country reacts to the deviation of the headline inflation from the long-term trend, empirical measure of output gap, and nominal exchange rate depreciation/appreciation pressures.[10] Nominal interest rate smoothness is also valued by the monetary authorities.

$$(1+i_{Ht}) = (1+i_{H,t-1})^{\rho_i} \left(\frac{1}{\beta} \Pi^{\Psi_1}_{Ht} \left(Y_{Ht}/Y_{H,t-1} \right)^{\Psi_2} \Delta S_t^{\Psi_3} \right)^{1-\rho_i} exp(\epsilon^i_{Ht}) \tag{1.28}$$

$$(1+i_{Ft}) = (1+i_{F,t-1})^{\rho_i} \left(\frac{1}{\beta} \Pi^{\Psi_1}_{Ft} \left(Y_{Ft}/Y_{F,t-1} \right)^{\Psi_2} \Delta S_t^{-\Psi_3} \right)^{1-\rho_i} exp(\epsilon^i_{Ft}) \tag{1.29}$$

Parameter ρ_i governs the smoothness, while parameters Ψ_1,Ψ_2, and Ψ_3 deter-

[9] Provided that initial asset holdings are appropriately chosen.

[10] The inflation rate is zero in steady state.

mine the strength of the response. The standard condition for the existence of the stable equilibrium in the NK literature known as the Taylor principle stipulates that the central bank responds more than one-for-one to inflation pressures; i.e., in the simplest case with no interest rate smoothing $\Psi_1 > 1$. This condition is also required in our setting.

In our baseline model we use year-on-year changes in inflation and nominal exchange rate rather than quarter-on-quarter changes as indicated in the rule above.[11].

Calibration

The real part of the model is calibrated following EW. We replicated the model in EW in order to be able to compare the results and to check that the extended model is consistent with the IRBC model. Our replication is very similar to that of the benchmark paper, but there are some differences. First, we had to use different values for the adjustment costs parameters to match the volatility of durable consumption investment and the volatility of business investment in the replicated model. Second, our computed value of the preference parameter used to calibrate the steady-state labor supply is somewhat larger (7.5 compared to 5.8). Due to the small difference in calibration, rounding errors in some parameters, and different solution methodology, our replication results differ but not significantly.[12]

Our simulations show that nominal price rigidities in the extended model amplify the volatility of the variables. Since price adjustments are limited in the short term, some of the adjustment occurs through the quantities of the variables rather than their prices. Moreover, traded durable goods are very sensitive to relative price changes that may stem from variation in exchange rate. This is a problem since the volatility of imported durable goods can be much higher than the volatility of those used domestically even when the average volatility of the two is close to the measured aggregate volatility in the data. Such a mismatch in volatility occurs when the adjustment costs parameters are the same across the imported and domestically used durable consumption or investment goods. However, if we allow them to differ so that the volatility of each of the subcomponents matches the average aggregate value, the problem disappears. This is illustrated in equations (1.30) and (1.31) below.

[11] Year-on-year change is related to quarter-on-quarter change as follows $\Pi 4_{Kt} = (\prod_{j=0}^{3} \Pi_{Kt-j})^{\frac{1}{4}}$.

[12] Baseline calibration of the parameters for the full model is summarized in Table 3.1 in Appendix 1A.

$$\Delta_H^K = \frac{\phi_1}{2}\frac{(d_H^K - \delta_d D_H^K)^2}{D_H}, \tag{1.30}$$

$$\Lambda_H^{JK} = \frac{\phi_2}{2}\frac{(I_H^{JK} - \delta_d K_H^{JK})^2}{K_H^J}. \tag{1.31}$$

Δ_H^K and Λ_H^{JK} are the adjustment costs for durable goods and capital goods in the home country. Note that Parameters ϕ_1 and ϕ_2 determine the magnitude of the costs and are chosen so that the volatility of aggregate durable goods and investment goods correspond to their empirical values. Note that in above specification, they are not allowed to depend on the country of origin (K) and the sector (J) that they are used in.[13] However, as we argued above, the performance of the model is significantly improved if ϕ_1 and ϕ_2 are allowed to depend on where the durable goods were originally produced and where they are used; i.e., we need to have ϕ_K and ϕ_{JK}.

We have some additional parameters due to additional features of the model that include the intermediate sector with monopolistic competition and the price-setting subject to Calvo constraints. The elasticity of substitution between the intermediate goods is set at the standard value found in the literature (Galí, 2009; Lubik and Schorfheide, 2006) implying a steady-state markup of 10%. The Calvo probability of (non-)adjustment parameters μ_N,μ_D and μ_M for the nondurable, the home-produced durable and the imported durable sectors respectively are set to generate average price duration of 3 quarters in the benchmark calibration. We also experiment with alternative degrees on nominal ridigities across the sectors.

As noted earlier, monetary policy is modeled using the Taylor-type response rule. The monetary authorities respond to the deviation of inflation from the steady state and the empirical measure of output gap. We also allow the policy rate response to the exchange rate depreciation. The Taylor rule parameters are calibrated based on Erceg and Levin (2006). This is consistent with the calibration of EW since they choose parameters related to the TFP shocks based on the same source.[14]

The interest rate smoothness parameter (ρ_i) is set to a value of 0.79, implying

[13]The sector of use is applicable for the investment goods only as they can be used in durable and nondurable production sectors.

[14]Erceg and Levin (2006) estimate the parameters that determine persistence and variance-covariance of the technology shocks in the durable and non-durable sectors using the method of moments. They match model-implied and empirical standard deviations, autocorrelations, and cross-correlations of sectoral outputs. It should be noted that there are some differences in terms of the definitions of the national accounts components in the models used by Erceg and Levin (2006) and EW. For example, Erceg and Levin abstract from capital accumulation and include residential investment in durable consumption, while EW model capital accumulation and abstract from residential investment. Thus, the use of the parameters of the technology shocks in their model may be considered an approximation.

a significant level of preference for smoothness at the central bank. The response parameter to inflation (Ψ_1) is set to $0.63/(1-\rho_i)$, implying a response to inflation of 3.05 consistent with Taylor principle. The response parameter for output gap (Ψ_2) and the reaction to the exchange rate depreciation (Ψ_3) are set to 0 in the benchmark parametrization, to make the model comparable to the benchmark NK model in Erceg et al. (2008).

As discussed, the NK model typically features additional shocks compared to IRBC setup. Interesting examples relevant for this setup include preference, investment, and labor supply shocks. However, for simplicity, we look at only the monetary policy shock and TFP shocks in the durable and nondurable sectors in our benchmark simulations. The monetary policy shock that is at the heart of the NK framework may induce negative comovement between the real imports and exports or, alternatively, may strengthen the positive comovement. We set the standard deviation of the monetary policy shock to 0.35% – a value used by Erceg and Levin (2006). On the other hand, the shocks to TFP shocks in durable and nondurable sectors tend to generate positively correlated real trade aggregates. The standard deviations and cross correlations of the shocks are taken from EW and Erceg and Levin (2006)

4 Results and Discussion

Our initial objective was to take the detailed structure used in EW to the NK framework and see if such a modification would improve the ability of the standard NK model to account for the dynamics in the international dimension. The answer to this question is not obvious. First, as the example in Barsky et al. (2007) illustrates, durable consumption goods and nominal rigidities do not necessarily constitute a good match from the modeling perspective. Second, the NK framework has richer shock structure, and additional shocks may generate counterfactual movements in the trade variables compared to the standard shocks in the RBC framework. Nevertheless, we found that our baseline two-country NK model with durable consumption goods and capital goods is able to replicate observed high volatility and positive comovement of exports and imports. Moreover, the model matches key moments for domestic variables and reproduces the basic conventional interest rate channel of the monetary policy. Our simulation results that include key volatility and comovement characteristics and the impulse response functions of the model are presented in Table 1.1 and Figures 1.2 to 1.4 below.[15] These results are robust under alternative monetary policy specifications. We have experimented with different values of nom-

[15] A full set of impulse responses including the responses to the TFP shock in the nondurables sector can be found in Appendix 1B.

Table 1.1: Simulation Results: Volatility and Comovement

	Panel A. Standard deviations relative to that of real GDP							
	C	I	DC	L	M	X	NX	Q
Data	0.798	2.890	2.983	0.670	3.335	2.626	0.250	2.432
Benchmark	1.066	2.514	2.998	1.239	3.288	3.288	0.219	0.558
Benchmark NCD	0.847	2.458	0.556	1.306	1.421	1.421	0.127	0.459
EW (2011)	0.878	2.594	2.473	0.547	2.633	2.678	0.337	1.262
EW (2011) Rep.	0.621	2.890	2.984	0.530	3.420	3.420	0.162	1.101
EW (2011) NCD	0.629	2.900	0.938	0.549	3.575	3.575	0.201	1.024
LS (2006)	0.303	...	...	3.859	0.155	0.239	0.492	1.167
EGG (2008)	1.408	0.762	...	3.185	0.771	0.739	0.652	1.192
EGG (2008) FL	0.471	2.429	...	5.541	2.105	2.071	1.459	3.441

	Panel B. Correlation with real GDP					
	M	X	NX	corr(M,X)	$\sigma_{Y,Y}$	$\sigma_{C,C}$
Data	0.827	0.415	-0.467	0.194	0.680	0.600
Benchmark	0.426	0.032	-0.420	0.558	0.180	0.173
Benchmark NCD	0.512	-0.044	-0.447	0.128	0.035	0.037
EW (2011)	0.606	0.411	-0.187	0.421	0.010	-0.170
EW (2011) Rep.	0.618	0.670	0.162	0.850	0.089	0.033
EW (2011) NCD	0.405	0.861	0.729	0.761	0.105	0.036
LS (2006)	0.324	0.462	0.323	0.791	0.089	0.623
EGG (2008)	0.620	0.373	-0.311	0.776	0.097	0.009
EGG (2008) FL	0.775	0.774	-0.019	0.862	0.347	-0.037

Note: All variables logged (except for NX) and HP filtered with smoothing parameter set to standard quarterly value of 1600. Variables: C – nondurable consumption; I business investment; DC – durable consumption investment; L – labor hours; M real imports; X – real exports; NX – net exports over GDP; Q – real exchange rate. Rows: Data – data from EW, c.f. Table 6 on p. 46; Benchmark – our extended model with durable consumption and investment goods, and nominal sector; Benchmark NCD – our model with fully depreciating durable consumption goods; EW (2011) – results from EW, c.f. Table 6, p. 46; EW (2011) Rep. – our replication of the results from EW; EW (2011) NCD – same as EW (2011) Rep. but with fully depreciating durable consumption goods. LS(2006) - results from our replication of Lubik and Schorfheide (2006); EGG (2008) – results based on the SIGMA model in Erceg et al. (2008); EGG (2008) FL – SIGMA model from Erceg et al. (2008) with forward-looking agents only; i.e., the share of Hand-to-Mouth Households is set to zero.

inal interest rate smoothing parameter and the parameters that govern the response of monetary policy to the empirical measure of output gap and the exchange rate depreciation.

The second rows of panels A and B of Table 1.1 labeled "Benchmark" show key data related to volatility and comovement of domestic and international variables from our benchmark model. The moments are computed based on the first-order approximation of the nonlinear model and filtered using the Hodrick-Prescott filter with a standard value of 1600 for the quarterly frequency. It is natural to compare the simulation results from the models to the corresponding data for the U.S. economy. Thus, as an additional benchmark, we reproduce the data taken from Table 6 (p. 46) in EW in the first rows of each of the panel in Table 1.1. Their computations are based on the U.S. national accounts data spanning 1973Q1 to 2006Q3. Though we do not have a perfect match for every item, we can see that both exports and

imports from the baseline model are much more volatile than the output and display positive correlation. The volatility of net exports is very close to the value observed in the U.S. data. Investment in capital goods and durable consumption goods is almost three times as volatile as the output. The trade variables are procyclical, while the net exports is countercyclical. These predictions of the model match the data characteristics rather well in these dimensions.

However, the benchmark model does not perform so well along a few dimensions. First, the volatility of nondurable consumption is too high compared to the data. Second, the volatility of the real exchange rate is significantly smaller compared to the data. Some of the open-economy models face a similar real exchange rate disconnect problem and add an additional shock to the UIP equation in order to increase the volatility of the variable (e.g., Lubik and Schorfheide (2006) discussed below). This is also the case for EW. Though the reduced volatility of the real exchange rate is a step back in matching the observed value, this is also not surprising since the prices are not allowed to adjust immediately to the shocks due to the constraints in price-setting faced by the intermediate producers. We do not add an additional shock to the UIP condition since this would likely amplify the substitution effect between exports and imports leading to negative correlation between the two. Finally, exports are strongly procyclical in the data. The benchmark model does generate real exports that are positively correlated with output, but the correlation is low.

EW demonstrate that a standard NK model summarized in their appendix is not able to simultaneously account for the high volatility and positive comovement of trade. However, can we say the same for a more elaborate yet standard NK model? In other words, the question is about the proper definition of the term "standard model."

First, we replicated a relatively simple NK model from Lubik and Schorfheide (2006). This is a two-country model with nominal price (but not wage) rigidities and incomplete pass-through. It does not explicitly model capital goods or durable consumption goods. This is one of the first two-country NK models estimated on U.S. data using the Bayesian methods. The simulation results are shown in Table 1.1 in the rows labeled "LS(2006)." We can see that the model fails to account for the high volatility of exports and imports. Its performance is better in terms of the comovement of the trade variables as both exports and imports are procyclical and positively correlated. On the other hand, net exports are not countercyclical. Thus, we can conclude that this model is not able to account for the dynamics of trade variables.

The next step was to compare our benchmark to a more elaborate medium-scale NK model.

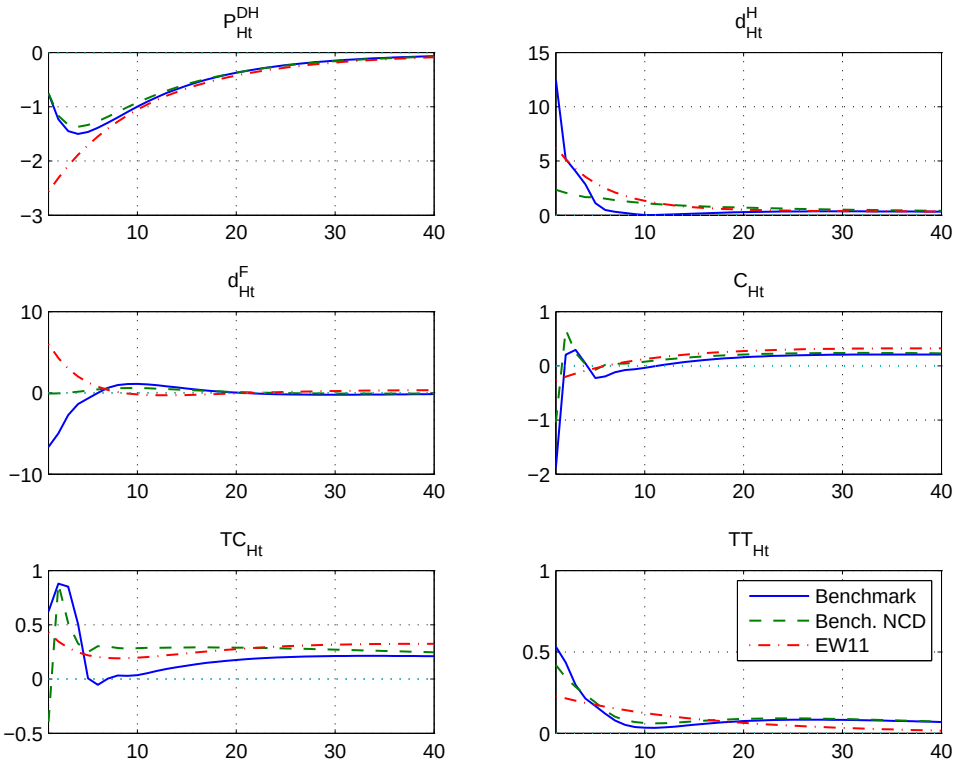

Figure 1.2: Impulse responses to 1 standard deviation TFP shock in durables sector (% deviation from steady state). Variables: P^{DH}_{Ht} relative price of home-produced durable goods; d^{H}_{Ht} investment in home-produced durable consumption; d^{F}_{Ht} investment in foreign-produced durable consumption; C_{Ht} nondurable consumption; TC_{Ht} total consumption; TT_{Ht} terms of trade – price of foreign-produced durable goods relative to home-produced durables goods. All variables are for the home country unless otherwise indicated.

4.1 Comparison of Benchmark Model with SIGMA Model

We decided to use the SIGMA model in Erceg et al. (2008) for a number of reasons. First, the model is used by the Federal Reserve (Fed) for policy analysis and comparison with its FRB/Global model. This adds to the credibility of the statement that it can be considered a "standard" NK model. Second, the version of the SIGMA model analyzed in Erceg et al. (2008) is designed to match the empirical characteristics of the trade variables and is a relatively simple modification of a one-sector model in this dimension. The shares of traded goods in the production of investment goods are calibrated in an empirically realistic way without introducing additional production sectors; i.e., in each country, there is only one sector of the producers of intermediate goods, and the distinction between consumption and investment goods is introduced only during the aggregation process.[16] This contrasts with the separate durable and nondurable sectors of intermediate producers in our benchmark model.

[16]Erceg et al. (2008) consider two different specifications of the SIGMA model: (1) Disaggregated trade (DT) specification with realistic share of imported goods in the production of capital goods; (2) Absorption-based trade (AT) specification, where the driving variable of exports and imports is aggregate absorption. They consider DT specification as the benchmark specification. We compare the results from our benchmark model to the DT version of the SIGMA model.

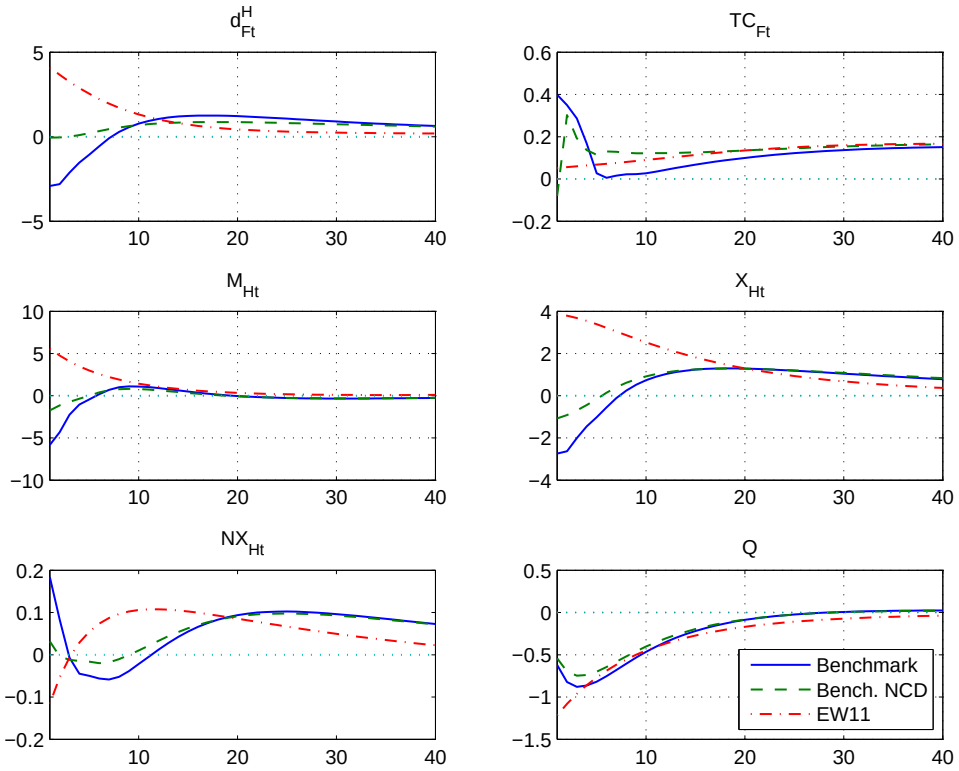

Figure 1.3: Impulse responses to 1 standard deviation TFP shock in durables sector (cont., % deviation from steady state). Variables: d^H_{Ft} investment in home-produced durable consumption goods in foreign country; TC_{Ft} foreign total consumption; M_{Ht} real imports; X_{Ht} real exports; NX_{Ht} nex exports relative to GDP; Q_t real exchange rate (increase is deppreciation). All variables are for the home country unless otherwise indicated.

Thus, we would like to compare our model to one that aims to matching similar data characteristics but with a less detailed model structure related to capital and consumer durable goods. The additional convenience associated with this model is that the code with its implementation is available from Wieland et al. (2012).

There are some further differences between our benchmark model and the SIGMA model. First, besides the optimizing (forward-looking) households, the latter model includes "hand-to-mouth" (Keynesian) households that consume their current income. This is used to achieve more realistic fiscal multipliers. Second, wages are subject to nominal rigidities in Erceg et al. (2008), but they are flexible in our benchmark model. Third, the SIGMA model introduces additional adjustment costs when switching between domestically-produced and imported goods to make the import share of investment and consumption goods insensitive to import price variations in the short run. Both the SIGMA and our benchmark models include rather standard investment adjustment costs. Fourth, the SIGMA model is not stationary but displays balanced growth path. It contains a much richer structure of permanent and transitory shocks. Some of the shocks affect the growth rate of the variables and have permanent effects on the levels of the variables. In order to make the models comparable, we matched the types and the standard deviations of the shocks to those

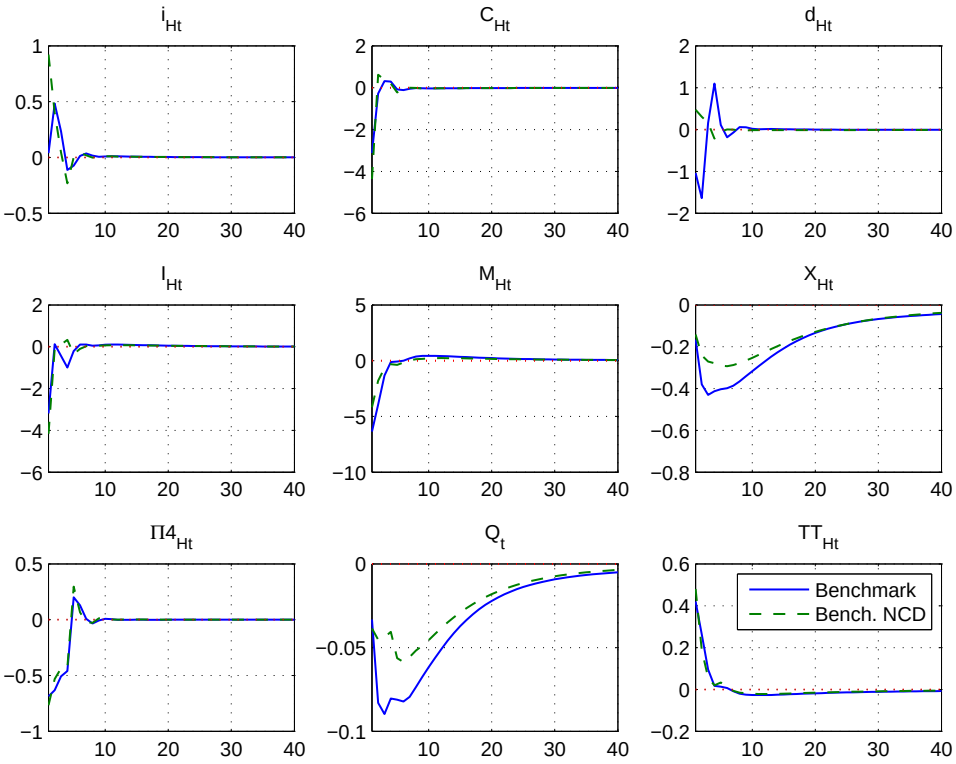

Figure 1.4: Impulse responses to 1 standard deviation monetary policy shock. (% deviation from steady state). Variables: i_{Ht} nominal exchange rate, p.a.; d_{Ht} durable consumption investment; I_{Ht} business investment; Y_{Ht} GDP; $\Pi 4_{Ht}$ year-on-year headline inflation; Q_t real exchange rate. TT_{Ht} terms of trade - price of imports devided by price of exports. All variables are for the home country unless otherwise indicated.

in our baseline model. For simplicity, we concentrate on TFP and monetary policy shocks (all other shocks are disabled). Given that the SIGMA model effectively has only one intermediate production sector in each country, we calibrate the exogenous TFP process in the SIGMA model based on the TFP process in the nondurables sector in the benchmark model. Finally, it is worth noting that the specification of the monetary policy and the parameters of the Taylor rule are very similar across these two models, thus, we did not make any adjustment to the Taylor rule in the SIGMA model.

The data in the row labeled "EGG (2008)" are generated from the SIGMA model with the disaggregated trade (DT) specification in Erceg et al. (2008). If we compare the results from the SIGMA model to those from our benchmark model and the data for the U.S., we will see that it cannot match the the volatility of the trade found in the data. Investment is not volatile enough, while nondurable consumption exhibits excessive volatility. On the other hand, the comovement statistics are consistent with their empirical counterparts. However, the performance of the model can be improved if we set the share of Keynesian households to zero. As can be seen from the selected impulse responses from the model in Figure 1.5, nondurable consumption is too volatile due to the presence of Keynesian households.

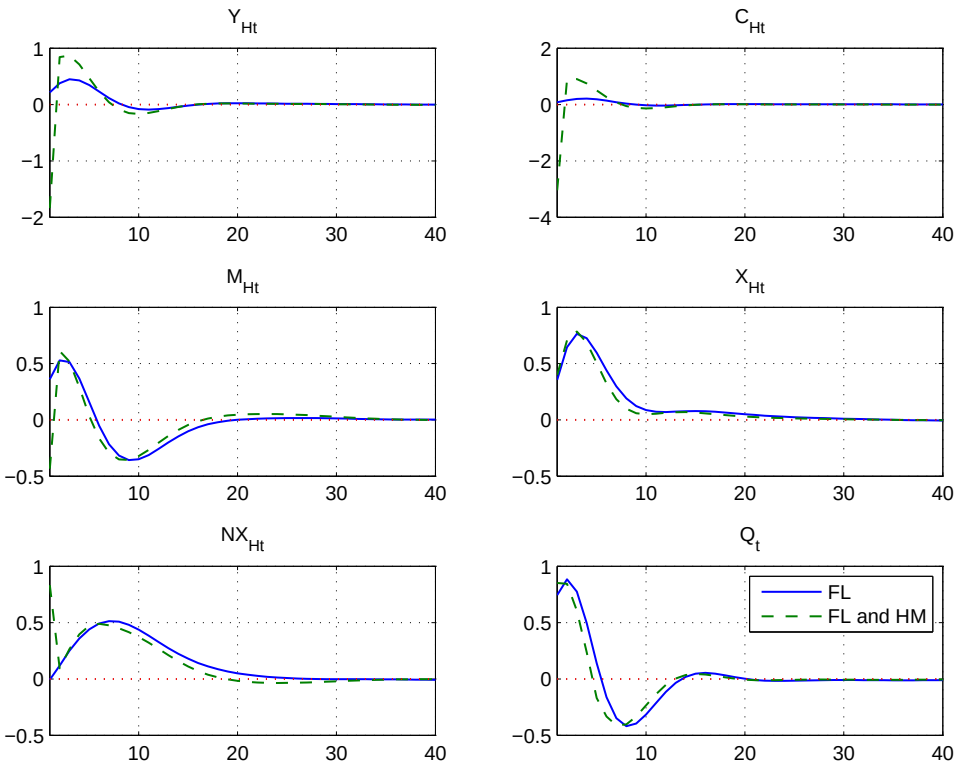

Figure 1.5: Impulse responses to 1 standard deviation TFP shock in SIGMA model (% deviation from steady state). Variables: Y_{Ht} GDP; C_{Ht} nondurable consumption; M_{Ht} real imports; X_{Ht} real exports; NX_{Ht} net exports divided by GDP; Q_t real exchange rate (increase is deppreciation). All variables are for the home country unless otherwise indicated. FL – model with forward-looking households only. FL and HM – full model that includes hand-to-mouth households and forward-looking households.

Our benchmark model performs rather well, though the performance of the SIGMA model without the hand-to-mouth households is also good. The latter model is able to match the positive comovement of the trade variables and countercyclical net exports. Though the volatility of the trade variables is still below the observed values in the data, there is significant improvement compared to the full SIGMA model. On the other hand, the modified SIGMA model matches the volatility of nondurable consumption and real exchange rate better compared to the benchmark model. The modified SIGMA model performs better than the model with Keynesian households, we will therefore concentrate on the former version.

Given the high share of durable goods traded and based on insights from their theoretical framework, Erceg et al. (2008) argue that *domestic and foreign investment shocks play an important role in driving the trade variables.* Moreover, they argue that such shocks may induce substantial trade adjustment even with minimal movements in the exchange rate. This is referred to as the "activity channel." In contrast, the authors demonstrate that consumption shocks induce trade flow adjustments associated with real exchange rate changes. The activity channel emphasized by Erceg et al. (2008) is more consistent with the fact that the trade variables are

positively correlated, as the movements in exchange rates would likely induce negative comovement between the exports and imports due to the substitution effect. However, the impulse responses to investment shocks and consumption shocks reported in Erceg et al. (2008) (*c.f.* Figures 4 to 6 on pages 2641-2645 in that paper) show that the SIGMA model implies that exports and imports move in different directions after the economy experiences a shock. Thus, though the adjustment in quantities through the activity channel of investment shocks seems to be a reasonable driver of the trade flows at first glance, the implications of the SIGMA model in terms of the changes in exports and imports after such shocks is not consistent with the positive comovement found in the data. Thus, either different types of shocks need to be considered or the activity channel of the SIGMA model needs to be modified to account for the positive comovement.

If we look at the impulse responses to the shocks of the level of TFP process in Figure 1.5 and the monetary policy shock (not shown), we can see that the SIGMA model implies that the exports and imports move in the same direction. This is also true for our benchmark model. Thus, our exercise suggests that these types of shocks may generate empirically realistic dynamics of the trade flows.

4.2 Comparison with EW and Sensitivity to Changes in Depreciation Rate

In order to check the consistency of our model, we also include the results from the EW model, which is a foundation of the real side of our extended model. The simulation results reproduced from the original paper (EW) and those based on our replication of that model are displayed in rows labeled "EW (2011)" and "EW (2011) Rep." As discussed above, there are some differences between the original and the replicated results due to small differences in calibrated adjustment costs and the solution method. However, the the results are qualitatively and quantitatively close. If we compare the EW and the benchmark models, we can see that the performance of the extended model is worse than that of EW along a few dimensions, but it is worth noting that the benchmark model is additionally able to reproduce the standard monetary transmission channel (as we will show below).

As an additional exercise, we investigate the sensitivity of the model to changes in the depreciation rate of consumer durables. As discussed above Baxter (1996) found that durable consumption goods do not constitute a quantitatively important propagation mechanism in a closed-economy RBC framework, since the simulations show that the depreciation rate parameter for consumer durables has a small effect on the overall dynamics of the model economy. Table 1.1 contains the results based on the versions of the benchmark model and the EW model where we set the

rate of the depreciation of the durable consumption goods to one. The rows are correspondingly labeled as "Benchmark NCD" and "EW (2011) NCD."

We only investigate the role of consumer durables by allowing the durable consumer goods to depreciate fully within a period. The depreciation rate of capital goods is not changed. We do this exercise for the benchmark and EW models. Though the rate of depreciation is set to one, there is still some durability in consumer goods stemming from the fact that these goods are purchased one period before they are consumed. The main finding is that the durability of consumer goods matters in the benchmark model. As shown in the row labeled "Benchmark NCD" in Table 1.1, once the durability of consumer durable goods is reduced, the volatility of exports and imports is more than halved. Moreover, the comovement between these two variables is also reduced. Surprisingly, this is not the case for the EW model where the reduced durability does not have a similar impact on trade variables. The presence of the nominal side and nominal price rigidities amplifies the importance of durable consumption goods.

Figures 1.2 and 1.3 below show the response of selected variables to a one standard deviation TFP shock in the durable sector (the impulse response functions to a TFP shock in nondurables sector are similar and are show in Appendix 1B). The responses are in percentage deviations from the steady state. We compare three different specification. Besides the benchmark specification of the baseline model with consumer durables and capital goods, we show the impulse responses for a version of that model with fully depreciating consumer durable goods. We can see that durability in consumer goods significantly amplifies the responses of durable consumer goods to the TFP shock. The differences translate into the different responses of exports and imports, which are more subdued in the model with reduced durability.

Figures 1.2 and 1.3 also display the impulse responses from our replication of EW. As expected, the response of the price variables (relative prices, real exchange rate, and inflation rates) is smoother and more gradual as it takes time for the intermediate firms to adjust their prices after shocks hit the economy. One might expect that since the prices do not adjust immediately, much of the adjustment should come through adjustment in quantities. This is the case for many of the real variables in our benchmark model.

We are able to match the standard response of the variables to the monetary policy shock found in New Keynesian literature (Christiano et al., 1999; Boivin et al., 2010). Figure 1.4 on page 25 illustrates the monetary channel via the response of the key variables to a one standard deviation monetary policy shock (tightening). Once again we compare the benchmark model with and without durability in consumer goods. The nominal interest rate increases after a positive policy shock. Nondurable

consumption and business investment decline in response to the policy tightening. Investment in durable consumer goods initially react negatively but bounce back after a few periods. The erratic behavior of durable goods is also often a problem in closed-economy two-sector models that are not able to match the positive comovement between the consumer durables and nondurables (Barsky et al., 2007, 2003). Monacelli (2009) augments the standard model with borrowing constraints where the durable goods are used as collateral to account for the positive comovement of the two types of consumption goods in response to a monetary policy shock. In our case, the initial reaction of the investment in durable consumption is consistent with the data. However, we found that this reaction is not robust to alternative monetary policy specification.

Policy tightening and the contraction of the domestic real economy is followed by reduced inflation. As expected, the real exchange rate appreciates immediately after the increase in the nominal interest rate. Real imports and exports decline to move in the same direction. As discussed earlier, substitution and income effects are at work. Given that the pass-through of foreign prices is not instant, as the prices of imported goods are subject to nominal rigidities, only a part of the decrease in the price of imported goods is transmitted to the domestic economy after the appreciation of its currency. This reduces the substitution effect, making the exports and imports move in the same direction. This mechanism is also at work in the benchmark model. If we reduce the level of price rigidities in imported goods prices, we can generate negative correlation between exports and imports. The bottom-line is that the shocks to monetary policy combined with incomplete pass-through can also generate positive comovement in trade and amplify its volatility.

The model with full depreciation of consumer durables displays similar responses to monetary policy shock as the benchmark model. However, the magnitude of the response of the variables is significantly reduced. This was also reflected in the volatility of the variables in Table 1.1 above.

5 Conclusion

We study the role of trade in durable consumption goods and durable capital goods in a two-country, two-sector NK DSGE model. Despite its simple structure, the benchmark model with sticky prices performs rather well in matching the moments and impulse responses of real and nominal variables inside the country as well as in the international dimension. In particular, investment in capital and durable consumption goods are almost three times as volatile as the output. Consistent with earlier findings, we are able to match the high volatility of exports and imports, their procyclical behavior, and positive correlation. Moreover, the model is also able to

replicate the standard monetary channel.

First, we compare the results from our benchmark model with a relatively simple two-country NK model from Lubik and Schorfheide (2006). This model does not explicitly incorporate capital goods and durable consumption goods and was one of the first two-country NK models estimated on U.S. data. We find that the model cannot account for the high volatility of the trade observed in the data.

As a next step, we compare the performance of our benchmark model to that of a standard medium-scale NK model from Erceg et al. (2008). This is an elaborate model with some additional frictions such as nominal wage rigidities, habit persistence in consumption, and a share of Keynesian households. It is a version of the SIGMA model used by the U.S. Fed as a benchmark model modified to have a realistic share of capital goods in trade. The SIGMA model does not explicitly incorporate behavioral equations for durable consumption goods, but the share of durable consumption goods is included in the share of traded capital goods. We find that the performance of the SIGMA model is not as good as that of our benchmark model under its baseline calibration found in Erceg et al. (2008). However, after some adjustment (mainly after setting the share of Keynesian households to zero) the model performs performs well in matching the dynamics in domestic and international dimensions; the volatility of exports and imports still remains slightly below the values found in the data.

We study the role of durability in traded consumer goods by comparing the benchmark model with a version of a model that sets the depreciation rate of consumer durable goods (but not capital goods) to full depreciation within a period. Our simulations show that the volatility of exports and imports generated in the model with the reduced durability in consumer durable goods falls significantly short of the values observed in the data. The model with benchmark calibration is able to reproduce the level of empirically observed volatility.

When the depreciation rate of consumer durables is set to one in the version of the model with fully flexible prices, the dynamics of the model are not changed significantly in contrast to the model with sticky prices. Thus, the presence of nominal sector and monetary policy amplifies the role of consumer durable goods. It is well known that durable goods are very sensitive to changing prices as the consumers have more freedom to adjust this component over time. On the other hand, if the prices are sticky, changes are more persistent and thus elicit a stronger response from the durable goods.

The interest rate channel together with incomplete pass-through of import prices can be though of as an additional channel that can generate high volatility and positive comovement in trade in addition to the TFP channel discussed in the literature. Simulations in the baseline model show that the exports and imports respond to the

monetary policy shock in the same direction, provided that the pass-through of import prices is not complete. The tightening of monetary policy leads to reduced aggregate demand and currency appreciation. Exports become more expensive and fall over time. On the other hand, though imports become cheaper, the income effect reduces the demand for imported goods. If the pass-through of import prices is not complete, the latter effect dominates and imports fall moving in the same direction as exports.

Further areas of investigation include the following. First, we have considered only the monetary policy and TFP shocks, while an empirically-oriented medium scale NK DSGE model usually contains a richer set of shocks. Thus, it would be interesting to investigate the behavior of the model considered in this paper with additional shocks. Second, the model is calibrated based on previous studies, but it would be very interesting to estimate the model based on U.S. data. Finally, as discussed earlier, sectoral differences in the degree of nominal rigidities are important in the closed economy context. Thus, it is interesting to analyze the role of such differentials for the setup explored in this paper. This is especially relevant for the monetary transmission channel and the design of the monetary policy.

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1.A Baseline Calibration

Table A1.1: Baseline Calibration

Real Economy		
Parameter	Description	Value
α	Share of home-produced capital in total sectoral capital	0.5
β	Subjective discount factor	0.99
χ	Capital share in production	0.36
γ	Long-run elasticity of substitution between home and foreign capital	9.04
δ	Depreciation rate of capital	0.0159
δ_d	Depreciation rate of durable goods	0.05
μ	Share of durable consumption in total consumption basket	0.23
ν	Preference parameter for labor supply	1.65
ψ	Share of home-produced durable consumption in total durable consumption	0.5
ρ	Preference parameter.	5.83
$\rho^N_{A,H}$	AR parameter for A^N_H	0.87
$\rho^D_{A,H}$	AR parameter for A^D_H	0.90
$\rho^N_{A,F}$	AR parameter for A^N_F	0.87
$\rho^D_{A,F}$	AR parameter for A^D_F	0.90
σ	Inverse elasticity of substitution	2
θ	Long-run Elasticity of substitution between home and foreign durable consumption goods	6.86
τ	Iceberg cost of trade	0.1
ς	Long-run elasticity of substitution between durable and nondurable consumption goods	1.1
ϕ_1	Durable consumption adjustment cost	0.7
ϕ_2	Capital adjustment cost	5.29
Nominal Economy		
e	Elasticity of substitution between intermediate goods	11
μ_n	Calvo parameter for nondurable sector	2/3
μ_d	Calvo parameter for durable sector	2/3
μ_m	Calvo parameter for imports sector	2/3
ρ_i	Taylor rule parameter: interest rate smoothing	0.795
Ψ_1	Taylor rule parameter: response to inflation	3.05
Ψ_2	Taylor rule parameter: response to growth	0
Ψ_3	Taylor rule parameter: response to nominal exchange rate depreciation	0

1.B Impulse Responses for Extended Variables and Shocks

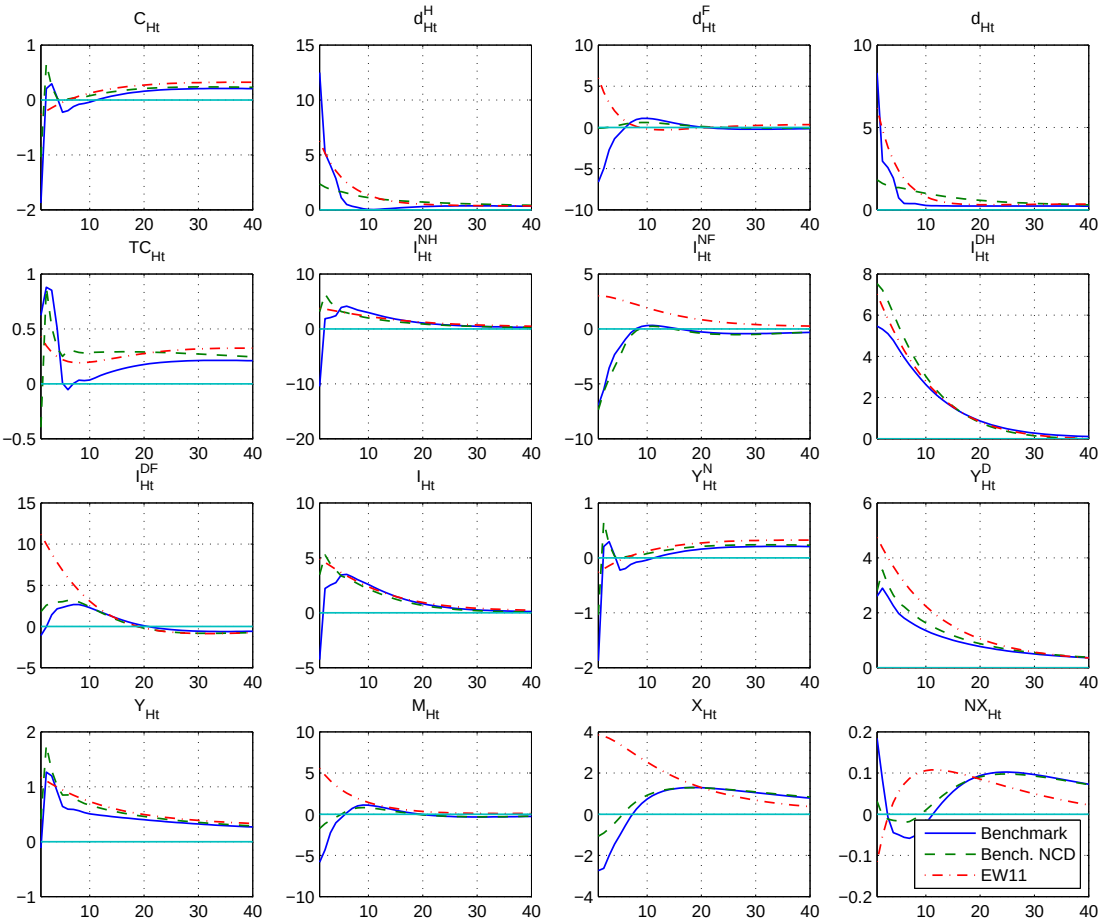

Figure B1.1: Impulse responses to 1 standard deviation TFP shock in durables sector (% deviation from steady state). Variables: C_H nondurable consumption; d_H^H investment in durable consumption goods produced at home; d_H^F investment in durable consumption goods produced abroad; d_H investment in durable consumption goods; TC_H total consumption; I_H^{NH} investment in capital produced at home and used in nondurables sector; I_H^{NF} investment in capital produced abroad and used in nondurables sector; I_H^{DH} investment in capital produced at home and used in durables sector; I_H^{DF} investment in capital produced abroad and used in durables sector; I_H investment in capital; Y_H^N output in nondurables sector; Y_H^D output in durables sector; Y_H total output; M_H real imports; X_H real exports; NX_H net exports divided by GDP. All variables are for the home country unless otherwise indicated.

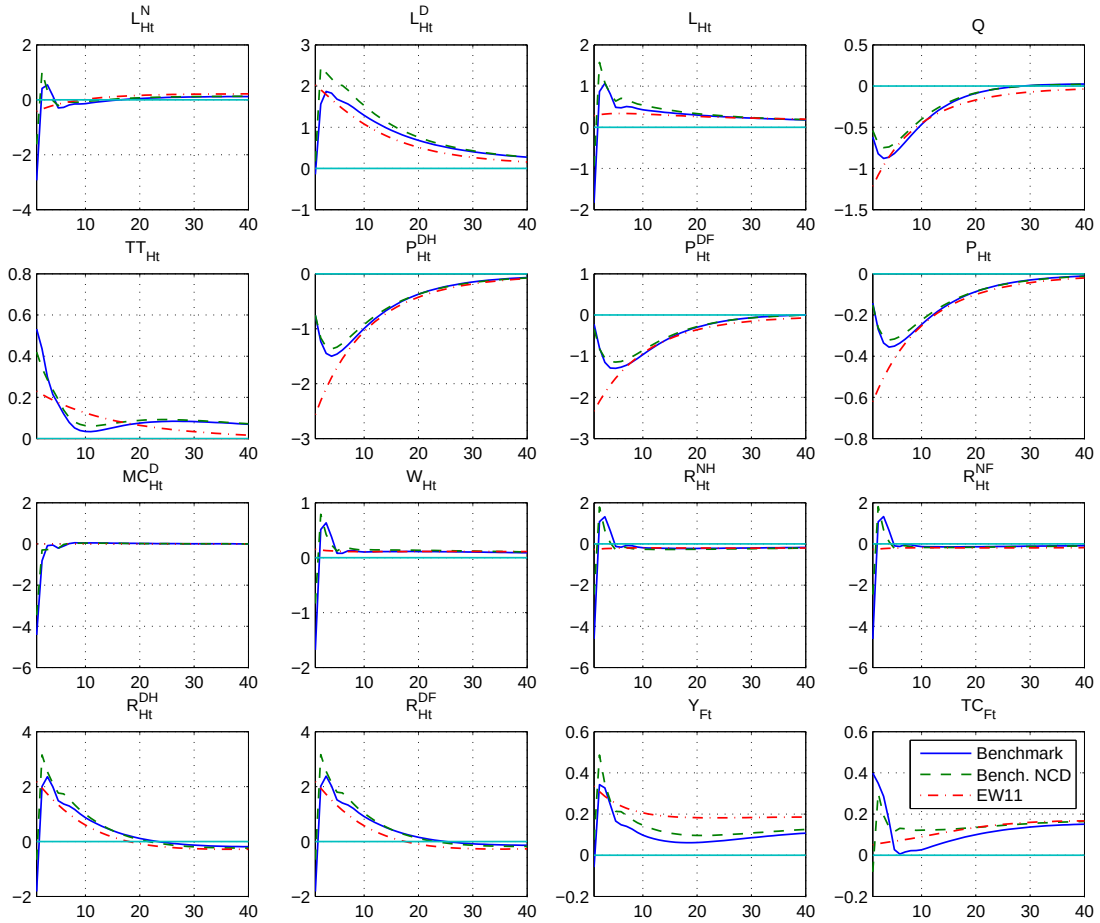

Figure B1.2: Impulse responses to 1 standard deviation TFP shock in durables sector (cont., % deviation from steady state). Variables: L_H^N labor supplied to nondurables sector; L_H^D labor supplied to durables sector; L_H total labor supplied; Q real exchange rate, increase is depreciation; TT_H terms of trade, relative price of imports over relative price of exports; P_H^{DH} real price of durable goods produced at home; P_H^{DF} real price of durable goods produced abroad; P_H real price index; MC_H^D real marginal cost in durables sector; W_H real wage; R_H^{NH} real rent paid for capital produced at home and used in nondurables sector; R_H^{NF} real rent paid for capital produced abroad and used in nondurables sector; R_H^{DH} real rent paid for capital produced at home and used in durables sector; R_H^{DF} real rent paid for capital produced abroad and used in durables sector; Y_F foreign output; TC_F foreign total consumtion. All variables are for the home country unless otherwise indicated. Real and relative prices are in terms on nondurable goods price in the same country.

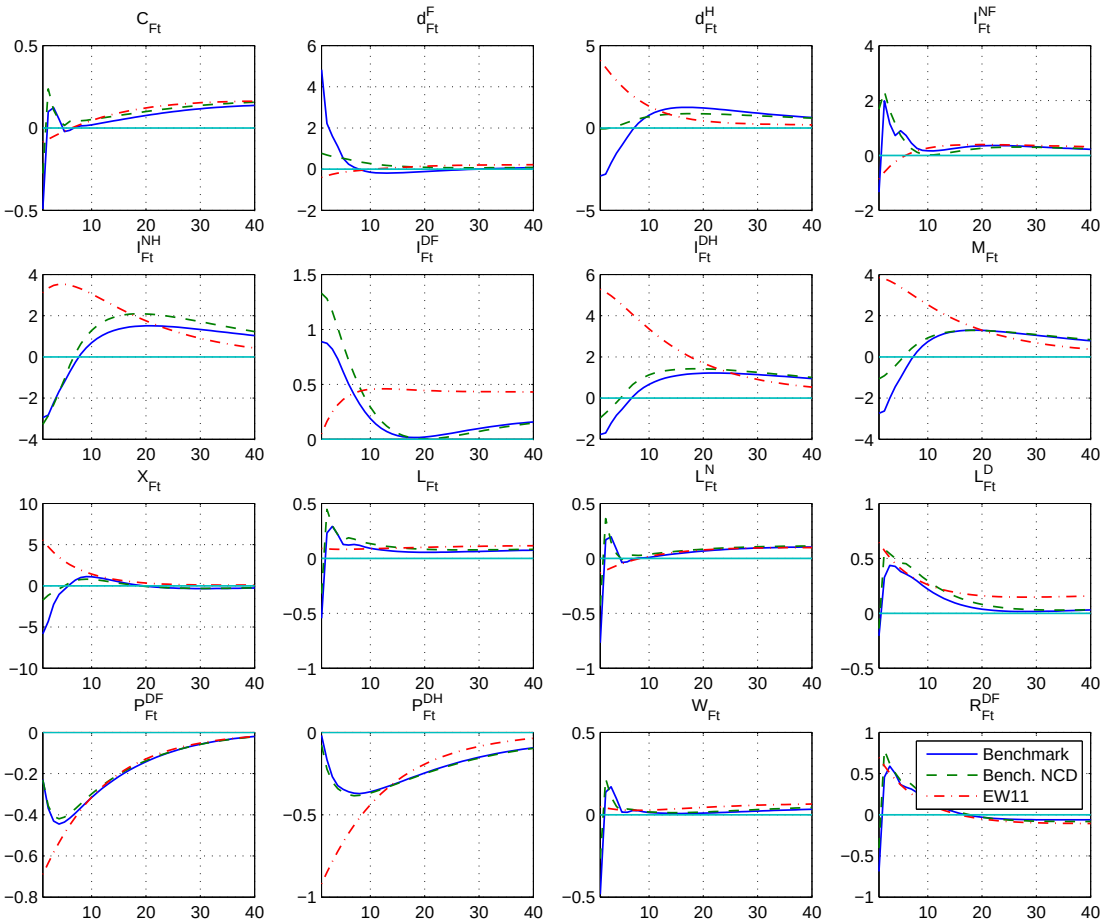

Figure B1.3: Impulse responses to 1 standard deviation TFP shock in durables sector (cont., % deviation from steady state). Variables: C_F foreign nondurable consumption; d_F^F foreign investment in durable consumption goods produced abroad; d_F^H foreign investment in durable consumption goods produced at home; I_F^{NF} foreign investment in capital produced abroad and used in nondurables sector; I_F^{NH} foreign investment in capital produced at home and used in nondurables sector; I_F^{DF} foreign investment in capital produced abroad and used in durables sector; I_F^{DH} foreign investment in capital produced at home and used in durables sector; M_F real foreign imports; X_F real foreign exports; L_F total labor supplied in foreign country; L_F^N labor supplied to nondurables sector in foreign country; L_F^D labor supplied to durables sector in foreign country; P_F^{DF} real price of durable goods abroad produced in foreign country; P_F^{DH} real price of durable goods abroad produced in home country; W_F real wage abroad; R_F^{DF} real rent paid abroad for the capital produced abroad and used in durables sector. Real and relative prices are in terms on nondurable goods price in the same country.

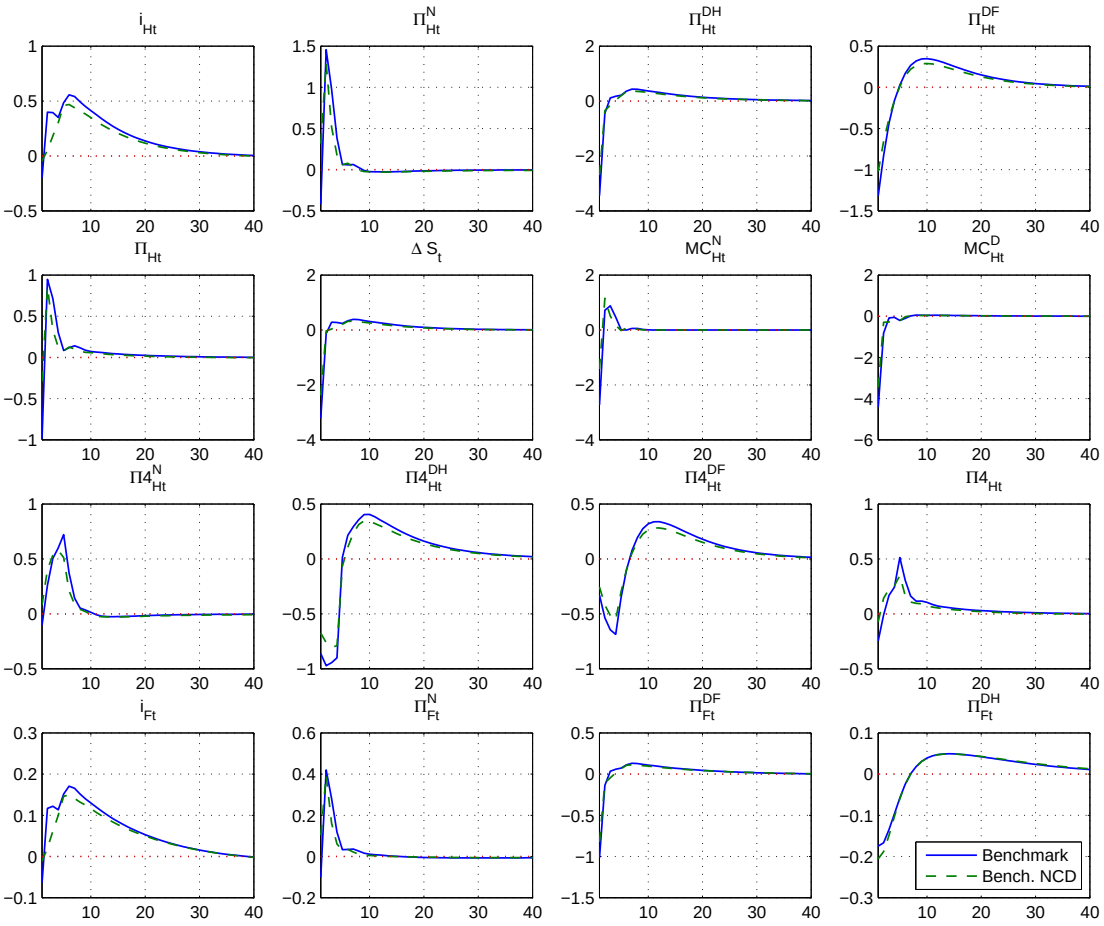

Figure B1.4: Impulse responses to 1 standard deviation TFP shock in durables sector (cont., % deviation from steady state). Variables: i_H nominal interest rate; Π_H^N nondurable goods price inflation; Π_H^{DH} home-produced durable goods price inflation; Π_H^{DF} foreign-produced durable goods price inflation; Π_H headline inflation; ΔS domestic currency depreciation; MC_H^N real marginal cost in nondruables sector; MC_H^D real marginal cost in durables sector; $\Pi 4_H^N$ nondurable goods price inflation, year-on-year; $\Pi 4_H^{DH}$ home-produced durable goods price inflation, year-on-year; $\Pi 4_H^{DF}$ foreign-produced durable goods price inflation, year-on-year; $\Pi 4_H$ headline inflation, year-on-year; i_F foreign nominal interest rate; Π_F^N foreign nondurable goods price inflation; Π_F^{DF} foreign-produced durable goods price inflation in foreign country; Π_F^{DH} home-produced durable goods price inflation in foreign country; All variables are for the home country unless otherwise indicated. Real or relative prices are in terms on nondurable goods price in the same country. All variables are for the home country unless otherwise indicated.

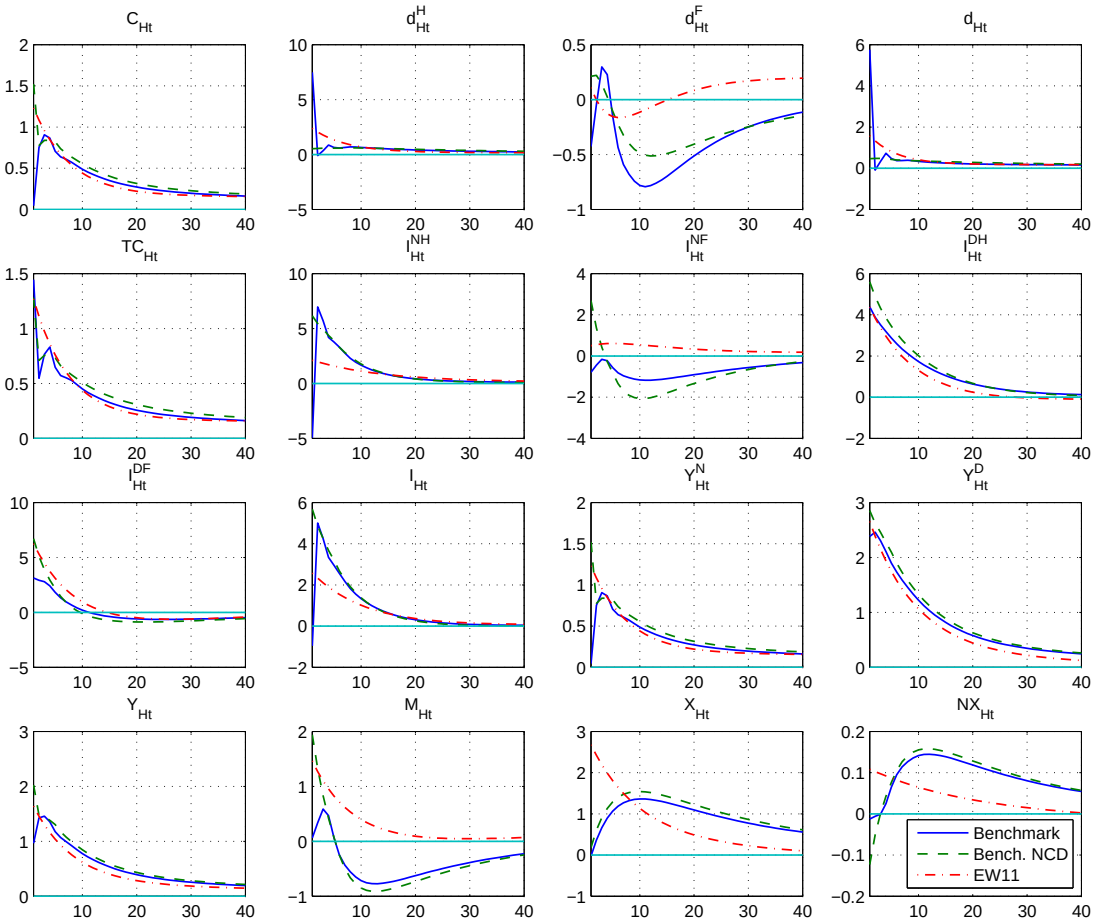

Figure B1.5: Impulse responses to 1 standard deviation TFP shock in nondurables sector (% deviation from steady state). Variables: C_H nondurable consumption; d_H^H investment in durable consumption goods produced at home; d_H^F investment in durable consumption goods produced abroad; d_H investment in durable consumption goods; TC_H total consumption; I_H^{NH} investment in capital produced at home and used in nondurables sector; I_H^{NF} investment in capital produced abroad and used in nondurables sector; I_H^{DH} investment in capital produced at home and used in durables sector; I_H^{DF} investment in capital produced abroad and used in durables sector; I_H investment in capital; Y_H^N output in nondurables sector; Y_H^D output in durables sector; Y_H total output; M_H real imports; X_H real exports; NX_H net exports divided by GDP. All variables are for the home country unless otherwise indicated.

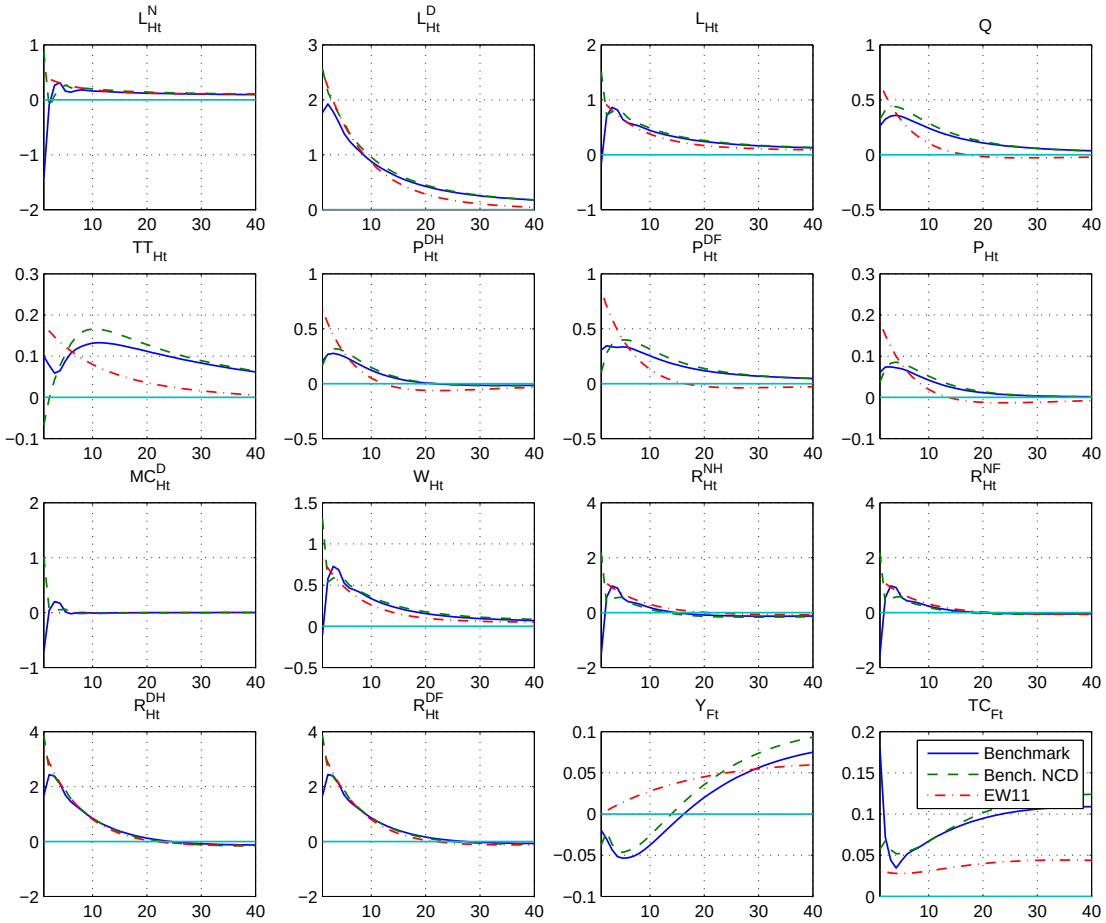

Figure B1.6: Impulse responses to 1 standard deviation TFP shock in nondurables sector (cont., % deviation from steady state). Variables: L_H^N labor supplied to nondurables sector; L_H^D labor supplied to durables sector; L_H total labor supplied; Q real exchange rate, increase is depreciation; TT_H terms of trade, relative price of imports over relative price of exports; P_H^{DH} real price of durable goods produced at home; P_H^{DF} real price of durable goods produced abroad; P_H real price index; MC_H^D real marginal cost in durables sector; W_H real wage; R_H^{NH} real rent paid for capital produced at home and used in nondurables sector; R_H^{NF} real rent paid for capital produced abroad and used in nondurables sector; R_H^{DH} real rent paid for capital produced at home and used in durables sector; R_H^{DF} real rent paid for capital produced abroad and used in durables sector; Y_F foreign output; TC_F foreign total consumtion. All variables are for the home country unless otherwise indicated. Real and relative prices are in terms on nondurable goods price in the same country.

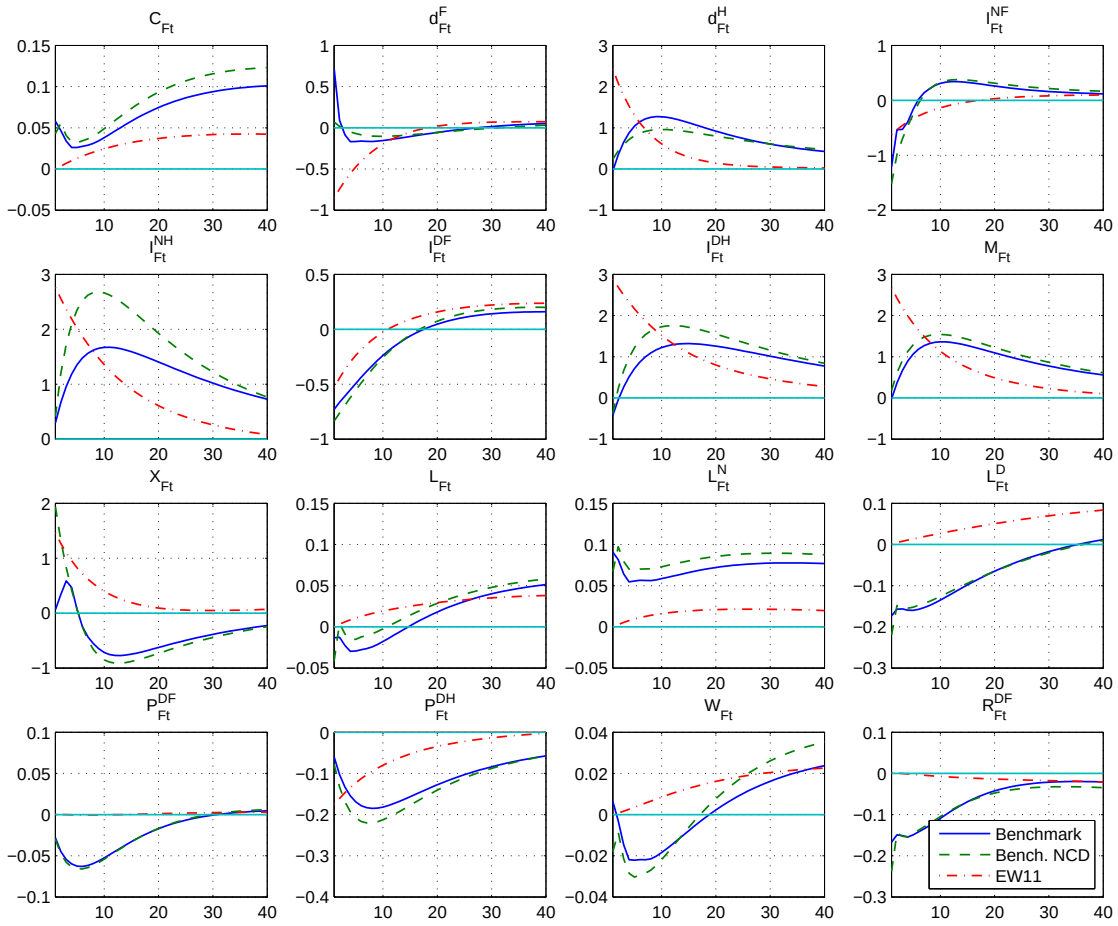

Figure B1.7: Impulse responses to 1 standard deviation TFP shock in nondurables sector (cont., % deviation from steady state). Variables: C_F foreign nondurable consumption; d_F^F foreign investment in durable consumption goods produced abroad; d_F^H foreign investment in durable consumption goods produced at home; I_F^{NF} foreign investment in capital produced abroad and used in nondurables sector; I_F^{NH} foreign investment in capital produced at home and used in nondurables sector; I_F^{DF} foreign investment in capital produced abroad and used in durables sector; I_F^{DH} foreign investment in capital produced at home and used in durables sector; M_F real foreign imports; X_F real foreign exports; L_F total labor supplied in foreign country; L_F^N labor supplied to nondurables sector in foreign country; L_F^D labor supplied to durables sector in foreign country; P_F^{DF} real price of durable goods abroad produced in foreign country; P_F^{DH} real price of durable goods abroad produced in home country; W_F real wage abroad; R_F^{DF} real rent paid abroad for the capital produced abroad and used in durables sector. Real and relative prices are in terms on nondurable goods price in the same country.

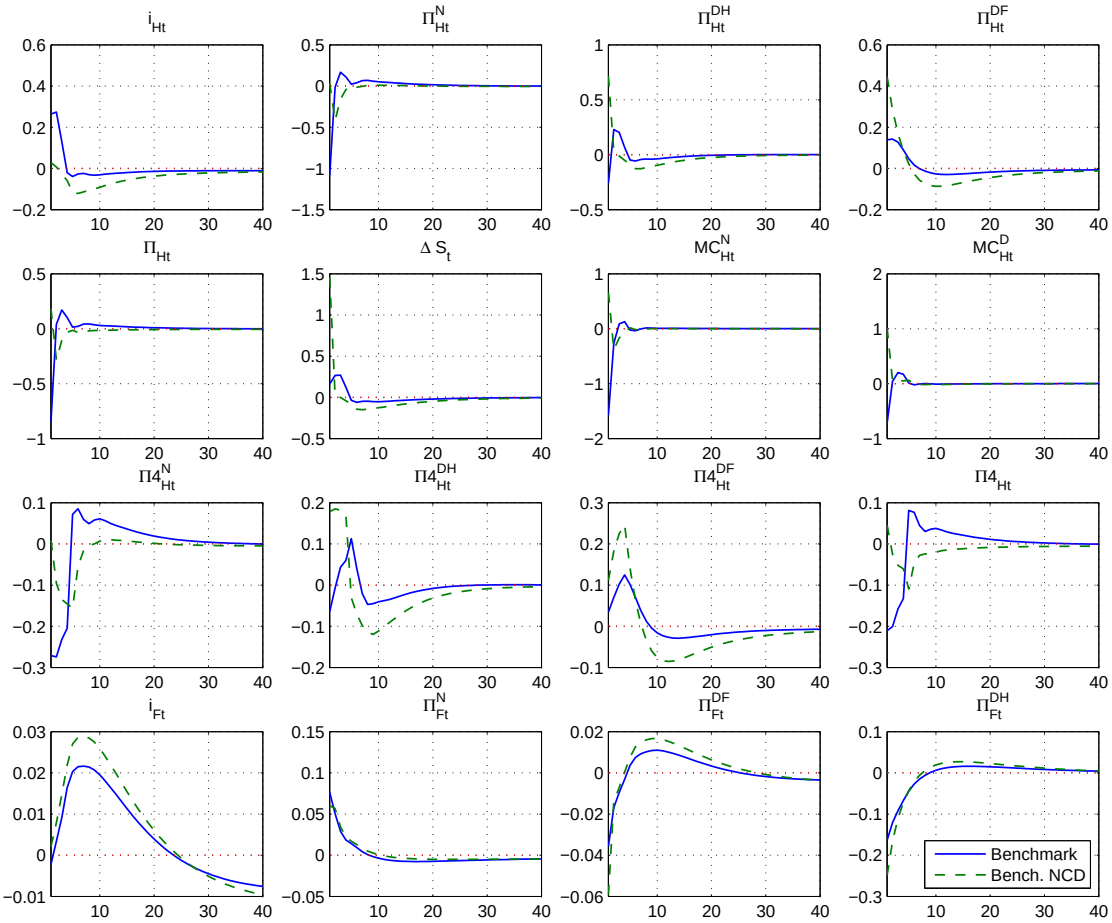

Figure B1.8: Impulse responses to 1 standard deviation TFP shock in nondurables sector (cont., % deviation from steady state). Variables: i_H nominal interest rate; Π_H^N nondurable goods price inflation; Π_H^{DH} home-produced durable goods price inflation; Π_H^{DF} foreign-produced durable goods price inflation; Π_H headline inflation; ΔS domestic currency depreciation; MC_H^N real marginal cost in nondruables sector; MC_H^D real marginal cost in durables sector; $\Pi 4_H^N$ nondurable goods price inflation, year-on-year; $\Pi 4_H^{DH}$ home-produced durable goods price inflation, year-on-year; $\Pi 4_H^{DF}$ foreign-produced durable goods price inflation, year-on-year; $\Pi 4_H$ headline inflation, year-on-year; i_F foreign nominal interest rate; Π_F^N foreign nondurable goods price inflation; Π_F^{DF} foreign-produced durable goods price inflation in foreign country; Π_F^{DH} home-produced durable goods price inflation in foreign country; All variables are for the home country unless otherwise indicated. Real and relative prices are in terms on nondurable goods price in the same country. All variables are for the home country unless otherwise indicated.

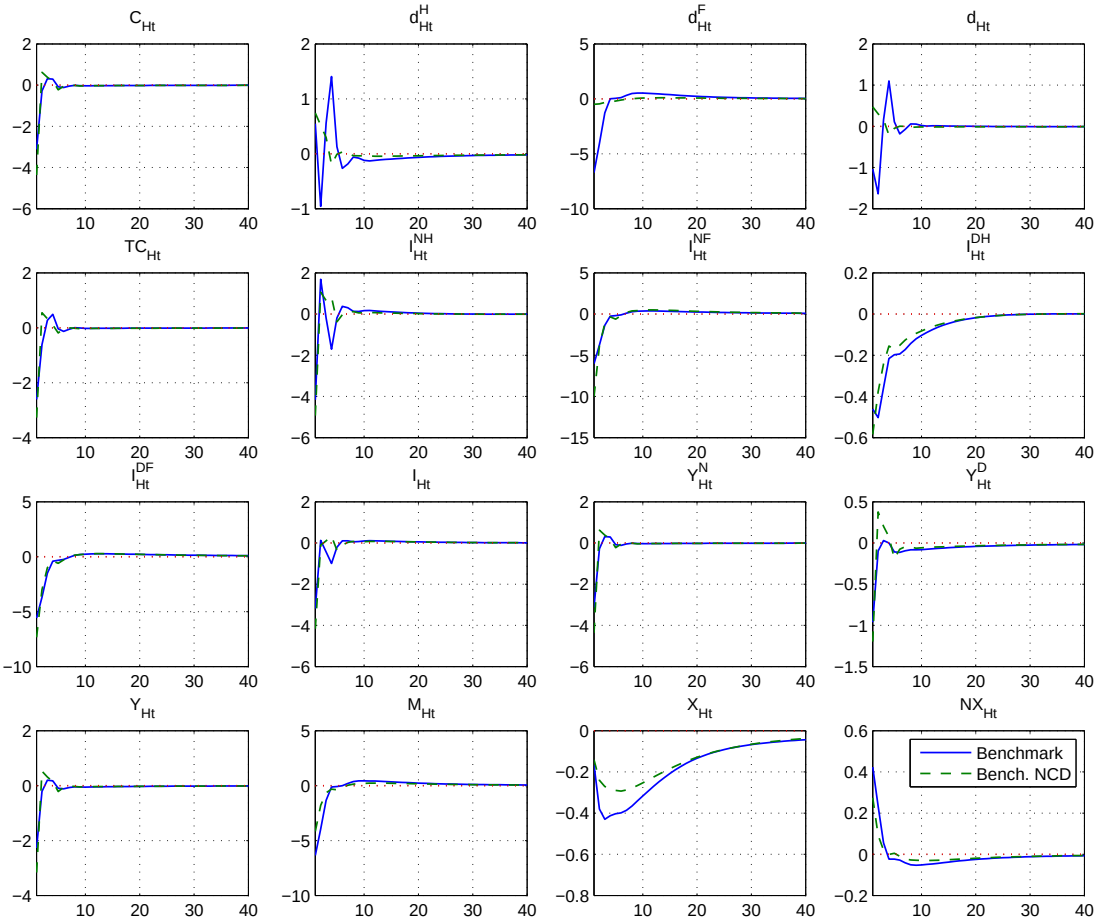

Figure B1.9: Impulse responses to 1 standard deviation monetary policy shock (% deviation from steady state). Variables: C_H nondurable consumption; d_H^H investment in durable consumption goods produced at home; d_H^F investment in durable consumption goods produced abroad; d_H investment in durable consumption goods; TC_H total consumption; I_H^{NH} investment in capital produced at home and used in nondurables sector; I_H^{NF} investment in capital produced abroad and used in nondurables sector; I_H^{DH} investment in capital produced at home and used in durables sector; I_H^{DF} investment in capital produced abroad and used in durables sector; I_H investment in capital; Y_H^N output in nondurables sector; Y_H^D output in durables sector; Y_H total output; M_H real imports; X_H real exports; NX_H net exports divided by GDP. All variables are for the home country unless otherwise indicated.

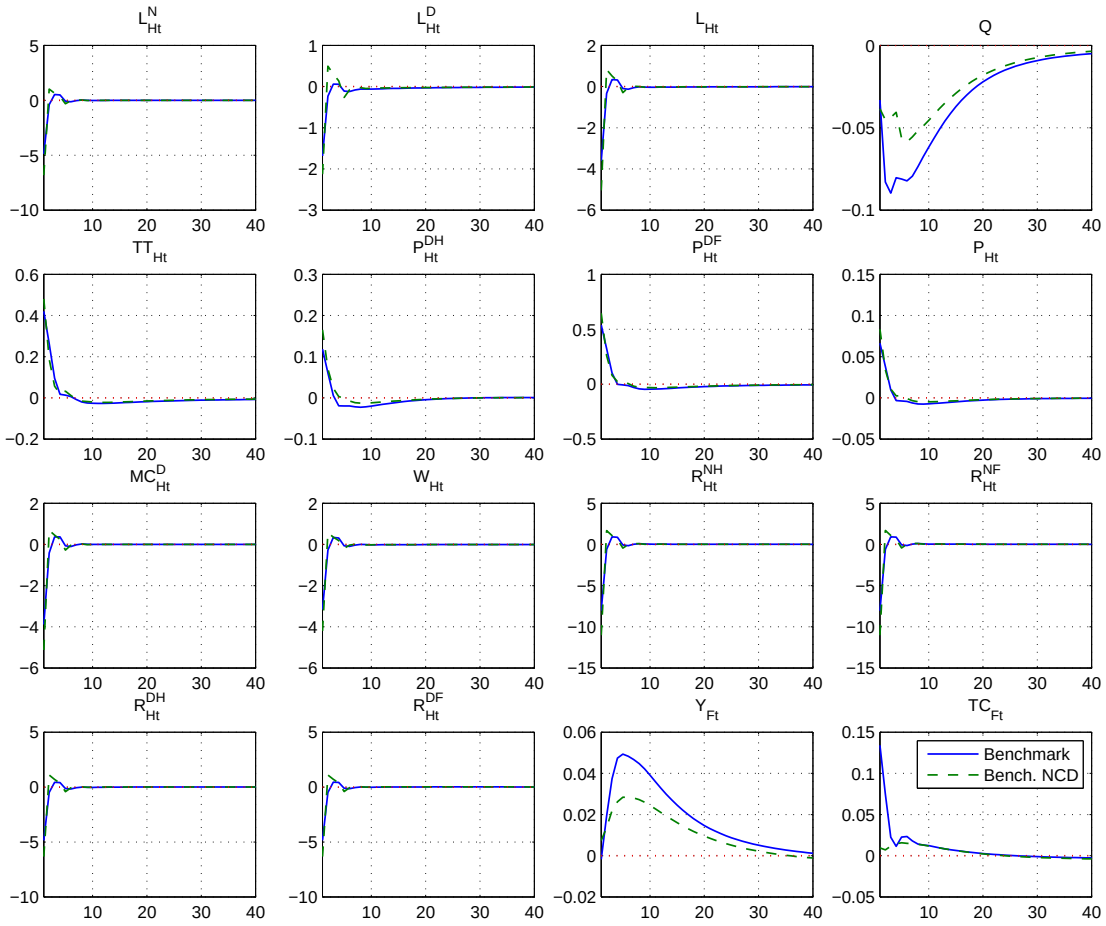

Figure B1.10: Impulse responses to 1 standard deviation monetary policy shock (cont., % deviation from steady state). Variables: L_H^N labor supplied to nondurables sector; L_H^D labor supplied to durables sector; L_H total labor supplied; Q real exchange rate, increase is depreciation; TT_H terms of trade, relative price of imports over relative price of exports; P_H^{DH} real price of durable goods produced at home; P_H^{DF} real price of durable goods produced abroad; P_H real price index; MC_H^D real marginal cost in durables sector; W_H real wage; R_H^{NH} real rent paid for capital produced at home and used in nondurables sector; R_H^{NF} real rent paid for capital produced abroad and used in nondurables sector; R_H^{DH} real rent paid for capital produced at home and used in durables sector; R_H^{DF} real rent paid for capital produced abroad and used in durables sector; Y_F foreign output; TC_F foreign total consumtion. All variables are for the home country unless otherwise indicated. Real and relative prices are in terms on nondurable goods price in the same country.

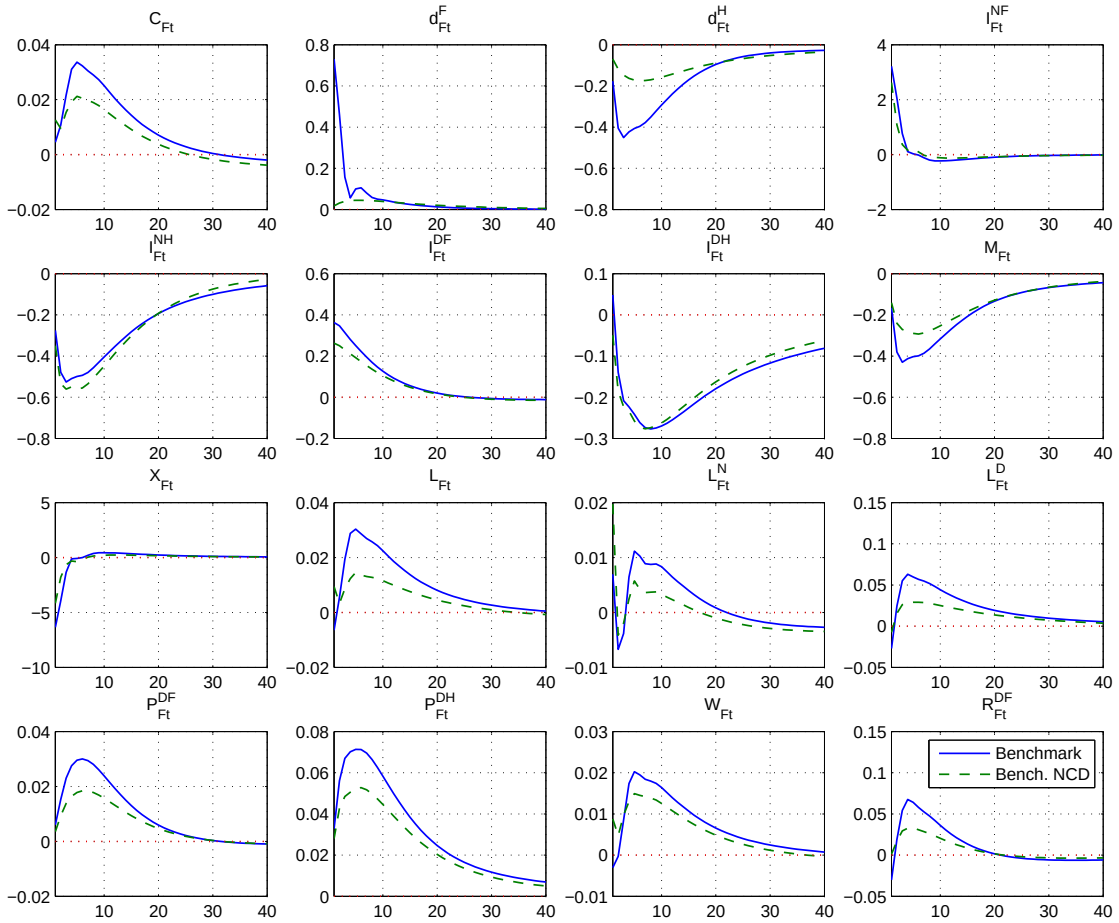

Figure B1.11: Impulse responses to 1 standard deviation monetary policy shock (cont., % deviation from steady state). Variables: C_F foreign nondurable consumption; d_F^F foreign investment in durable consumption goods produced abroad; d_F^H foreign investment in durable consumption goods produced at home; I_F^{NF} foreign investment in capital produced abroad and used in nondurables sector; I_F^{NH} foreign investment in capital produced at home and used in nondurables sector; I_F^{DF} foreign investment in capital produced abroad and used in durables sector; I_F^{DH} foreign investment in capital produced at home and used in durables sector; M_F real foreign imports; X_F real foreign exports; L_F total labor supplied in foreign country; L_F^N labor supplied to nondurables sector in foreign country; L_F^D labor supplied to durables sector in foreign country; P_F^{DF} real price of durable goods abroad produced in foreign country; P_F^{DH} real price of durable goods abroad produced in home country; W_F real wage abroad; R_F^{DF} real rent paid abroad for the capital produced abroad and used in durables sector. Real and relative prices are in terms on nondurable goods price in the same country.

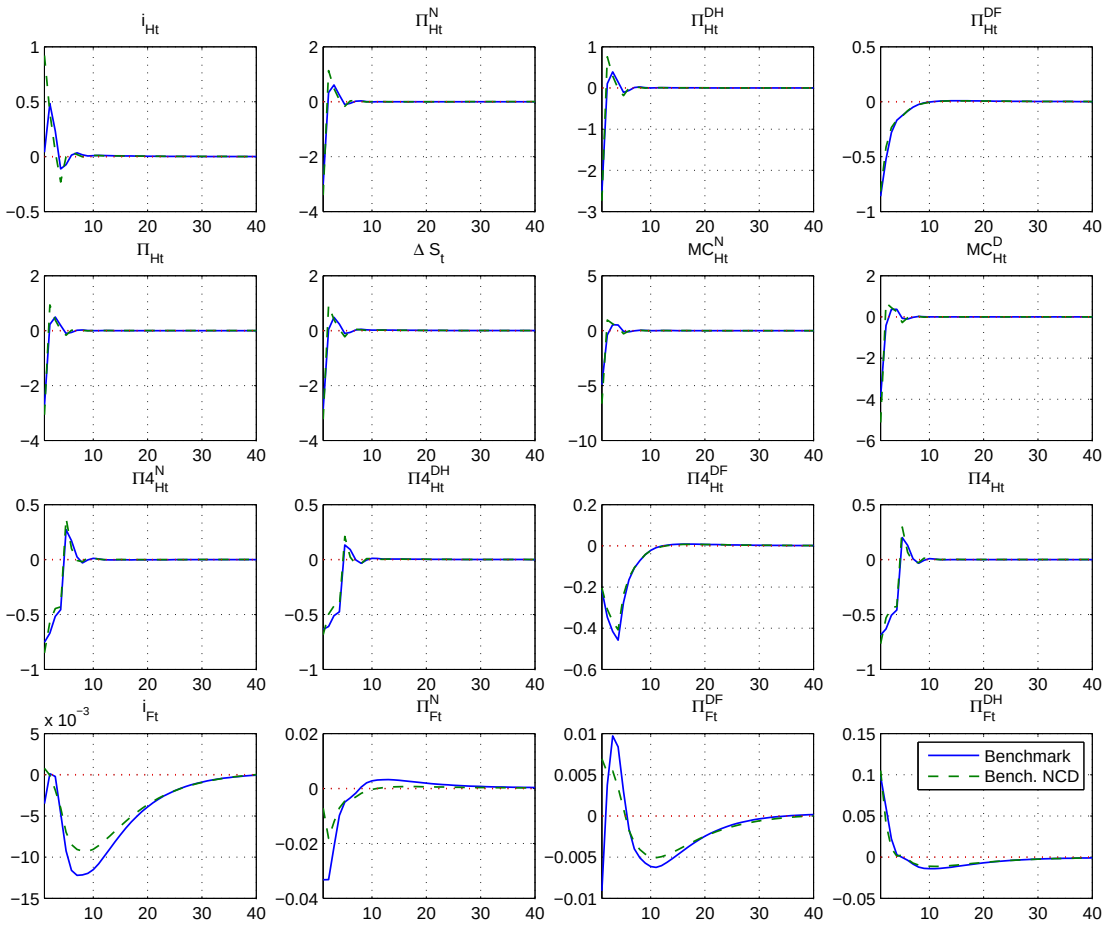

Figure B1.12: Impulse responses to 1 standard deviation monetary policy shock (cont., % deviation from steady state). Variables: i_H nominal interest rate; Π_H^N nondurable goods price inflation; Π_H^{DH} home-produced durable goods price inflation; Π_H^{DF} foreign-produced durable goods price inflation; Π_H headline inflation; ΔS domestic currency depreciation; MC_H^N real marginal cost in nondruables sector; MC_H^D real marginal cost in durables sector; $\Pi 4_H^N$ nondurable goods price inflation, year-on-year; $\Pi 4_H^{DH}$ home-produced durable goods price inflation, year-on-year; $\Pi 4_H^{DF}$ foreign-produced durable goods price inflation, year-on-year; $\Pi 4_H$ headline inflation, year-on-year; i_F foreign nominal interest rate; Π_F^N foreign nondurable goods price inflation; Π_F^{DF} foreign-produced durable goods price inflation in foreign country; Π_F^{DH} home-produced durable goods price inflation in foreign country; All variables are for the home country unless otherwise indicated. Real and relative prices are in terms on nondurable goods price in the same country. All variables are for the home country unless otherwise indicated.

Chapter 2

The Effect of Oil Price Shocks on Oil-Importing Developing Economies: The Cases of Georgia and Armenia

We study the impact of oil price fluctuations on oil-importing developing economies focusing on Armenia and Georgia as examples of small open economies. We explicitly model the world oil market and allow for fundamental oil shocks that originate from different sources such as oil supply disruptions or fluctuations in world economic activity (Kilian, 2009a). We use a structural vector autoregressive (SVAR) model for this purpose. We also examine overall energy flows and the plausible oil shock transmission mechanisms for the developing economies in the study. We document a number of interesting findings. First, consistent with the literature for developed economies, the identified impulse responses show that different types of oil shocks have different effect on the macroeconomy (with the oil shocks having a quantitatively small effect). Thus, accounting for underlying reasons for increases in oil prices is important even for small open economies. Second, given that oil-market-specific demand shocks, which are considered important drivers of world oil prices, do not lead to higher inflation and in some cases even reduce the GDP, the demand channel can be an important transmission factor. Third, we find that real oil price jumps stemming from accelerating world economic activity have a positive effect on inflation (the effect is only marginally significant for Armenia). Given the high share of food items in the headline CPI of the developing economies under study and evidence that food prices are also driven by dynamics of world economic activity (Baumeister and Kilian, 2013), this result suggests that part of oil price shocks can be transmitted through food prices. Finally, we find that the structure of energy flows and the pricing of natural gas matter for the transmission of oil shocks.

Keywords: SVAR, Business Cycles, Energy, Oil Shocks

JEL clasification: C32, E32, Q43

1 Introduction

Developments in oil prices are closely followed by the economists and policymakers around the world. Such special attention is motivated by the several observations: large fluctuations of energy prices and oil prices in particular; oil being an essential input for a wide spectrum of production processes in different sectors of the economy; low demand elasticity stemming from the key role of energy in the economy; and the experience of the 1970's when dual oil shock episodes were accompanied by recession and soaring inflation in the U.S. and many other developed economies (Bernanke, 2006; Kilian, 2008b).

Given the global nature of the market for crude oil, developments in oil prices are endogenous to global economic conditions (and *vice versa*). Clearly oil prices are endogenous relative to the state of large world economies such as the United States, but endogeneity is also an important factor to take into account when studying their impact on small open economies such as Armenia and Georgia. Given that these economies are integrated into the global economic patchwork and are also subject to changes in global economic activity through, for instance, the FDI, inflow of remittances, and demand for exports, treating the oil price series as a simple exogenous process is not likely to be informative about the true effect of oil price shocks.

The focus of the present study is to understand the effects of oil price shocks on a small, open, oil-importing economy, focusing on developing countries such as Armenia and Georgia. Our objective is to identify the impact of the oil shocks on developing economies and the factors that determine the nature of the impact. To answer these questions, we utilize a number of tools. We identify the effect of oil price fluctuations on the economy using a structural vector autoregressive (SVAR) model. Specifically, we estimate the magnitude and impact directions of oil shocks on key aggregate variables such as GDP, inflation, monetary policy rate, and exchange rates; and gauge the importance of oil price swings in aggregate fluctuations. The SVAR model allows for different types of fundamental shocks in the international oil market *a la* Kilian (2009a) (as discussed below), and we show that oil price shocks have different effects on the economies based on the source of changes in crude oil prices. In parallel to the SVAR model, we examine the structure of energy flows and the data for plausible transmission channels. This adds some credibility to the selection of the variables used for estimation and is important for the interpretation of the results from the structural model. We analyze the importance of different channels of transmission of oil price shocks based on the SVAR results and the available data for different channels. For instance, the role of monetary and fiscal policies are of interest. Finally, we argue that the structure of energy flows is an

important factor in understanding the effect over time and across the countries in our sample.

An oil price shock may be defined and identified in different ways. The conventional approach is to identify such a shock as an innovation to the level or nonlinear transformation of real or nominal crude oil price based on short-term response restrictions in SVAR models (Bernanke, Gertler, and Watson, 1997; Blanchard and Gali, 2007). A more recent approach (Kilian, 2009b) utilizes the SVAR model of the international oil market to identify different types of shocks that drive the price of crude oil. Such shocks stem from fundamental innovations due to oil supply shortages, global real economic activity, and oil-market-specific demand shifts. Interestingly, more than one such shocks may occur at a specific date (unlike the conventional approach where we are confined to a single shock), and we may observe no actual change in oil price if the different types of shocks cancel each other out. As mentioned above, one of the objectives of this paper is to understand whether differences in the sources of oil price shocks matter for small open economies such as Georgia and Armenia. Therefore, we use and compare both conventional and more recent definitions.[1,2]

In general, following the developments in the literature, the effects of oil price shocks may be better understood based on the three broad factors. First, as argued in the previous paragraph, *the source of the oil shock* matters, and it is necessary to decompose the oil price shocks based on the source. Second, various institutional features of the economy summarized by the *transmission mechanism* of oil shocks are considered an important determinant of their effects in the literature. Third, the *structure of energy flows* matters for understanding the effect through time and across countries. Though different strands of literature usually emphasize one of the broad factors, they are complementary rather than mutually exclusive. A brief description of the three factors follows.

[1]Similarly a related strand of literature that uses dynamic stochastic general equilibrium (DSGE) models rather than SVAR framework to study the effects of oil price changes defines an oil price shock as either a simple *ad hoc* innovation to the exogenously given oil price variable or develops a more sophisticated structural model of the international oil market in parallel to the artificial economy under study (Carlstrom and Fuerst, 2006; Bodenstein et al., 2012).

[2]Researchers have utilized various techniques to "isolate" the exogenous part of oil price change or to capture a nonlinear relationship between oil prices and the macroeconomy. Different measures of oil market indicators are used for this purpose. Simple oil price changes are still considered a useful shortcut given the price swings are large and rapid. For instance, Blanchard and Galí (2010) take this approach. A popular measure suggested by Hamilton (1996) – net oil price increase – is a nonlinear transformation of oil price that registers only the increase in nominal oil price from the largest value in the previous 4 quarters. The rationale for using this measure is that, as Hamilton (1996) argues, it captures the nonlinear relationship between the macroeconomy and oil price changes. Net oil price change is used as a benchmark measure by Bernanke et al. (1997). Other approaches include concentrating on positive oil price increases (Mork's measure) or on price increases associated with the dates of exogenous political events (see the discussion in Bernanke et al. (1997), p. 103).

A recent strand of literature (summarized in Kilian (2014)) argues that given the endogeneity of prices, the causal interpretation of innovations to oil prices is problematic. The reason for the increase in the oil price matters, and to understand the effect of a particular oil price shock on the macroeconomy, we need to understand the original reason for the shock. For example, if we observe a jump in oil prices as well as an accelerating global economy, we might expect a different effect on the economy compared to the case where we observe an increase in oil prices accompanied by news of crude oil supply shortfalls.

The effects of oil price swings may propagate through various channels of the transmission mechanism. The traditional channel explored in early literature is the inflation channel (also called the supply channel). Increased energy prices create inflationary pressures as the higher prices are reflected in the price of the final energy products. This is often referred to as the first-round effect. The effect may not stop at this stage and propagate further as the firms increase the price of their products in response to higher input prices (cost channel) and the consumers demand higher nominal wages in response to higher prices. This is the second-round effect (Bernanke, 2006). The transmission of the oil price shock through the cost channel may be amplified by microeconomic mechanisms such as time-varying markups and variable capital utilization (Rotemberg and Woodford, 1996; Finn, 2000; Segal, 2011) and reallocation effects Davis and Haltiwanger (2001).

A direct channel runs through the effect of the oil price shocks on aggregate demand (analogous to tax on consumption). On the one hand, consumption is affected due to reduced disposable income, increased precautionary savings, and delayed purchases of consumer durables. On the other hand, investment responds as a result of the reduced expected demand faced by firms (Bernanke, 2006; Kilian, 2008b).

An important factor in the transmission mechanism of oil shocks is the endogenous reaction of monetary policy (Bernanke et al., 1997; Blanchard and Galí, 2010; Segal, 2011). Monetary authorities may loosen or tighten their stance depending on the anticipated effect on aggregate demand and pass-through of increasing oil prices to domestic inflation.

A fiscal channel may be relevant in the context of developing countries since energy markets are often highly regulated in developing economies, and some of the impact of energy price fluctuations may be countered through fiscal measures. Nevertheless, the fiscal channel is rarely discussed in the context of advanced economies in the literature.

Which of the transmission mechanisms dominate in practice? Conventional theories emphasize the inflation channel. If the inflation channel is more important, we would expect rising inflation and declining output after a positive oil price jump

while keeping all else constant.[3] On the other hand, if the demand channel is stronger, we would expect reduced inflation and output.

The early studies on developed economies based on data from the 1970's argued in favor of the supply and reallocation channels and systematic monetary policy as an important transmission mechanism of oil price shifts. More recent research based on updated data revealed reduced quantitative effect of oil shocks on key macroeconomic variables. These studies explain the difference from the 1970's experience by improved monetary policy, diminishing frictions in labor market, and more flexible and less energy-intensive economies (Blanchard and Galí, 2010). An alternative explanation focuses on the endogeneity of oil prices with respect to global economic activity, implying that the original cause of a particular oil shock is the key to understanding the reaction of the economy (Kilian, 2008b, 2014). In the latter strand of research, the demand channel is considered to be an important transmission mechanism.

Existing literature concentrates on developed economies with the U.S. being the most popular. The studies do not reach consensus regarding the comparative importance of alternative channels, especially the role of the monetary policy (Blanchard and Galí (2010) compared to (Kilian, 2008b, 2014)).

A more limited number of studies analyzes the issue for the oil-importing developing economies. Only a handful of studies (e.g., Rasmussen and Roitman (2011)) offer a systematic treatment of this question and provide only limited analysis of the transmission mechanism, leaving this area open for further investigation. The transmission mechanism for emerging economies[4] may be different due to their less developed institutions, higher exposure to international shocks, and higher volatility (Frankel, 2011).

Weaker institutions translate into lower central bank credibility, and less competitive financial and goods sectors. Lower credibility, usually stemming from an earlier hyperinflation episode, may make it more likely that sudden oil price jumps will accelerate inflation through second-round effects. Additionally, less competitive banking sector, underdeveloped financial markets, and dollarization of the economy may lead to a weak interest rate channel. This may result in less effective monetary policy and stabilization policies in general.

In the context of this paper, on the one hand, the implication is that the impact of oil price swings may be more detrimental as there are fewer ways to counteract

[3]For simplicity assume that the price increase is due to an exogenous supply shortfall to keep the other variables fixed. If the central bank reacts to higher inflation assuming that the supply channel is the relevant transmission mechanism, some of the inflation is expected to be traded off for the output. We would still expect rising inflation and declining output in this case.

[4]I use the terms "emerging" and "developing" with respect to a country or an economy interchangeably.

the oil shocks (provided that this is required). On the other hand, different economic structure and energy intensity in emerging economies may make them less susceptible to adverse consequences.

A procyclical flow of foreign funds and procyclical fiscal policy may also change the effect of oil price fluctuations compared to developed countries. The former is also another factor that necessitates accounting for the endogeneity of oil prices and the original source of a shock.

Energy products are considered to be highly standardized and traded in close-to-competitive environments in developed economies (Aoki, 2001, p. 57). This has implications for the optimal policy reaction to price changes. However, the energy distribution markets are likely to be less competitive and transparent in emerging economies, due to less effective competition policy, sectoral regulation, weaker institutions in general, and higher corruption levels.

Additional objectives of the research include cross-country comparisons of transmission channels of oil price shocks and implications for policy design. The results of the study are intended to be of interest for the policymakers in the region. Our results may be useful from the modeling perspective, in particular, for modeling the external sector. A unified treatment of the topic may provide a convenient comparison through the region and an opportunity to assess the consistency of existing models.

The next section constitutes a review of relevant literature. A brief summary of methodology follows in section 3. We then look at the key regularities found in the data regarding the structure of energy flows and the dynamics of principal macroeconomic variables in the transmission channels. Next we present the results of the SVAR models. The final section concludes with a summary and review of the results.

2 Literature Review

The role of oil price fluctuations in the world market attracted considerable attention of researchers after two waves of oil shocks in the 1970's that were followed by widespread recession and high inflation in advanced economies.[5] Hamilton (1983) found that most U.S. recessions were preceded by significant jumps in oil prices up to 1980. A number of studies that followed found similar results for many other developed economies. Some textbook examples from the 1980's would "blame" oil shocks for the breakdown of the Phillips curve relationship and for stagflation.

Different approaches in the area may be grouped into *conventional* and *recent*

[5]Hamilton (2005); Segal (2011); Kilian (2008b, 2014) provide a comprehensive summary on the effects of the oil shocks for developed countries, although from different perspectives.

approaches. The conventional approach concentrates on a single type of oil shock that is usually considered to be caused by exogenous disruption of the oil supply. This approach uses the structure of the economy or the transmission mechanism to explain the key characteristics of the relationship between oil prices and the macroeconomy.

For example, as the standard neoclassical model was not able to quantitatively account for the observed decline in output in the 1970's, a number of studies tried to extend the model to add mechanisms that would amplify the impact of the oil price changes. Rotemberg and Woodford (1996) added imperfect competition and time-varying mark-ups, while Finn (2000) augmented the standard model with variable capital utilization. These studies found that their models were able to account for some shortfall in the response compared to the benchmark case. Models with capital-energy complementarities and capital adjustment costs were also tested and shown to imply larger effects of energy price fluctuations on the output (Atkeson and Kehoe, 1999). Other authors focused on the endogenous reaction of monetary policy. A seminal paper by Bernanke, Gertler, and Watson (1997) studies the importance of systematic monetary policy in accounting for the response of output and inflation to the oil shocks of the 70's using semistructural vector autoregressions as a primary tool. The authors estimate a monthly SVAR model and use it to conduct counterfactual experiments holding the monetary policy fixed. Interestingly, they find that a large portion (almost all in one case) of the decline in output after an oil price shock is explained by the endogenous reaction of the monetary policy. It noteworthy that there is no consensus on the role of monetary policy as later studies found no compelling evidence in the SVAR framework (Kilian and Lewis, 2011) and mixed evidence in DSGE setting (Leduc and Sill, 2004; Carlstrom and Fuerst, 2006; Blanchard and Galí, 2010).

A second example of the conventional approach is the excellent paper by Blanchard and Galí (2010), that first documents that the impact of oil price shocks has declined from 1970's through the 2000's and explains this change as due to changing transmission mechanism in developed economies over this period. In particular, they argue that improved monetary policy, diminishing frictions in the labor market, and more flexible and less energy-intensive economies have reduced the effects of oil price shocks.

As a third example of conventional theories, a related strand of research focuses on the reallocation effects induced by the energy price shifts to account for the asymmetric response of the output (Hamilton, 1988; Davis and Haltiwanger, 2001; Lee and Ni, 2002).

Unlike the conventional approach, a more recent approach argues that oil shocks originate from different sources and as a result have different effects on the econ-

omy, based on its type. The oil shock issues and examples discussed above may alternatively be explained by this theory.

In a series of papers, Kilian has emphasized the endogeneity of oil prices and argued that the changes in world oil prices may have different impacts on the economy depending on the original source of the change in the price itself (Kilian, 2008b, 2009b, 2014; Kilian and Lewis, 2011). He argues that a thought experiment of looking at the effect of oil prices while keeping everything else fixed is not well defined due to reverse causality from macroeconomic aggregates to the oil price and the fact that structural demand and supply shocks that affect the oil prices also influence the macroeconomic variables.

Kilian (2009a) decomposes a sudden rise in real oil prices based on 3 sources: (1) oil supply shocks, (2) global aggregate demand shocks, and (3) oil-market-specific demand shocks. Using a novel monthly measure of global economic activity based on freight rates Kilian identifies each of the listed shocks in a simple recursive SVAR framework. He estimates that aggregate demand and oil-specific demand shocks account for most of the historical variation in real oil prices. Furthermore, employing a simple univariate time series model, he estimates the impact of each of the shocks on U.S. growth and CPI inflation. He finds that oil supply shocks have limited impact on either GDP or inflation, while the two demand shocks result in persistent and significant declines in output and rises in inflation.

The finding that oil supply shocks account for only a small share of the variation in oil prices is also corroborated in a number of studies that measure the effect of oil supply disruption shock on oil prices. Oil shocks may also be measured based on oil production rather than on oil price. Dates of political events (such as the Iranian revolution or Gulf War) interacted with the reduction of oil supply may serve as an instrumental variable to oil price changes (Hamilton, 2003). Kilian (2008a) is interested in the effect of oil supply shocks on the key macroeconomic aggregates of G7 countries. He constructs a production based measure of shortfall based on country-specific actual series and counterfactual series calculated using the oil output growth rates in benchmark country groups not affected by specific supply shock episodes. The identified shocks are used in standard univariate time series regressions to estimate the impulse responses and to conduct historical simulations. Oil supply shocks identified in this manner are shown not to play am important role in crude oil price dynamics.

Comprehensive analysis of energy price swings on emerging economies and the associated transmission channels is rather limited. Rasmussen and Roitman (2011) study a large set of developed and developing countries (including oil-importers and oil-exporters) using dynamic panel data methods to control for the endogeneity of the oil prices. They look at the response of the cyclical component of GDP, imports,

and exports and find a relatively small effect of oil price jumps on oil-importing economies, though the effects increase as the energy intensity of imports increases. Interestingly, the raw correlations of oil price increases with GDP and trade variables is positive and sizable for most of the economies considered highlighting the importance of controlling for global economic activity.

3 Methodology

We proceed in two stages. In the first stage, we look at the relevant data on energy flows and transmission channels. *Though simple comovements in the data do not, in general, indicate causal relationships, such data analysis is useful for understanding the specificities of the developing economies, selection of the relevant variables and the structure of the model, and interpretation of results.* Second, we employ a recursively identified SVAR model to gauge the reaction of inflation, output, policy rates and monetary aggregates, and exchange rates to the oil price shocks as well as the importance of the shock in overall volatility of the series.

3.1 SVAR Model

SVAR models impose a relatively modest and straightforward structure on the data. Identification strategy involves placing restrictions on the relationships between the variables. Such restrictions may be classified into short-term, long-term, sign restrictions, and other approaches (Kilian, 2011; Christiano, Eichenbaum, and Evans, 1999).

The recursiveness assumption is a type of short-term identification strategy and requires that the variables ordered in the SVAR model do not respond to certain innovations instantaneously.

Consider the following simple SVAR model to illustrate the idea.

$$B_0 Y_t = B_1 Y_{t-1} + u_t, \tag{2.1}$$

where Y_t is a vector of variables; u_t is a vector of structural shocks, and B_0 and B_1 are parameter matrices. Note that B_0 governs the contemporaneous relationships between the variables. The values of the parameters in B_0 and B_1 matrices are, in general, unknown. We can only estimate the reduced form of the model of the following form.

$$Y_t = B_0^{-1} B_1 Y_{t-1} + B_0^{-1} u_t, \tag{2.2}$$

$$Y_t = A_1 Y_{t-1} + \epsilon_t. \tag{2.3}$$

Here ϵ_t is a vector with reduced form shocks, and A_1 is a matrix of reduced form coefficients. We can estimate the A_1 matrix and the variance-covariance matrix of the residuals, but in order to recover the structural relationships, we need to place additional restrictions on B_0; for example, we do not know the values of the parameters in B_0, but based on some external information (such as the characteristics of a particular market), we may assume that some of the elements of B_0 are zero. For a given ordering of the variables in Y_t, the recursiveness assumption implies that a variable contemporaneously reacts to its own structural shock and the structural shocks associated with the variables ordered before it. For instance, if the first element of Y_t is oil production growth, which is considered to be very inelastic in the short run, it will react in the current period only to shocks specific to the oil production process and will not be immediately influenced by other types of shocks, such as shocks to global economic conditions or economic states of particular macroeconomic variables.

$$\epsilon_t \epsilon_t' = B_0^{-1} u_t u_t' B_0^{-1\prime} \tag{2.4}$$

$$\Sigma_\epsilon = B_0^{-1} B_0^{-1\prime} \tag{2.5}$$

The recursiveness assumption is equivalent to Cholesky decomposition of the estimated variance-covariance matrix of the reduced form residuals.[6]

First, we estimate a simple quarterly model where we recursively identify the oil price shock as an innovation to the real price of oil. Though this specification does not allow us to identify the reaction of the economy to oil price shocks based on the underlying source in the world oil market, it is still a useful benchmark that allows us to look at the average response of the macroeconomic aggregates to a mixture of different types of oil shocks. Later, we utilize the model of world oil market developed in Kilian (2009a) and estimate a model that includes additional variables from the world oil market.

We estimate the benchmark model with five variables ordered in the following manner: world oil market indicator, CPI inflation, real GDP growth, monetary aggregate – M1 – growth, and exchange rate depreciation. The innovation to the oil market indicator is a measure of oil shock. We take real U.S. CPI deflated oil price

[6]The variance-covariance matrix of structural residuals is normalized to the identity matrix.

as the oil market indicator. Under the recursiveness assumption, we would require that the oil price does not respond to innovations to the other four variables in the same period. If the frequency of the series is high enough, this is a reasonable assumption even for large developed economies, where the dynamics of the local economy may in general influence global prices (Kilian and Vega, 2011). The recursiveness assumption is more credible for a monthly rather than quarterly frequency, but given the absence of output measure at the monthly frequency for the countries that we consider, this is still a useful approximation.

We take M1 and the bilateral local currency (LCY) per USD exchange rate as the measures of the stance of the monetary policy. While the monetary policy rate or an interbank money market rate would also serve an alternative measure of the monetary policy, the transition to formal inflation targeting is a relatively recent development for the countries in our sample, and either there are insufficiently historical series available for these variables or there is evidence of structural change. Nevertheless, we have also estimated the baseline model with alternative measures of the policy stance, such as the monetary base and filtered interbank interest rates, but our main results remain intact under the alternative specifications.[7] In general, data limitations and the relatively short sample make designing more complex policy measures and including additional dummy variables to account for possible structural shift in the policies infeasible. The nominal effective exchange rate (NEER) is an alternative to the USD/GEL rate, but given that the central bank intervenes most often in the USD market, we choose the bilateral exchange rate. The results are similar if we use the NEER.

The following equations illustrates the assumed relationship between the reduced-form and structural shocks in the benchmark model.

$$\begin{pmatrix} \epsilon_t^1 \\ \epsilon_t^2 \\ \epsilon_t^3 \\ \epsilon_t^4 \\ \epsilon_t^5 \end{pmatrix} = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 & 0 \\ a_{2,1} & a_{2,2} & 0 & 0 & 0 \\ a_{3,1} & a_{3,2} & a_{3,3} & 0 & 0 \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} & 0 \\ a_{5,1} & a_{5,2} & a_{5,3} & a_{5,4} & a_{5,5} \end{pmatrix} \begin{pmatrix} u_t^{Oil} \\ u_t^{GDP} \\ u_t^{CPI} \\ u_t^{M1} \\ u_t^{ER} \end{pmatrix} \tag{2.6}$$

Note that we assume that the real price of crude oil reacts only to its own shock in the current period. Domestic variables also react to an oil shock in the current period as well as other shocks depending on their order in the data vector. If we were solely interested in the reaction of the monetary policy, we could choose either to identify the model fully or to leave the domestic sector unidentified in which case we would have a semi-structural model. In the letter case, the ordering

[7] We filtered the interbank interest rate series to remove long-term downward trend

of the other variables above the monetary policy instrument would be irrelevant (Christiano et al., 1999, p. 82). In the former case, consistent with the standard channel of monetary transmission, the assumption implies that in the current period, GDP reacts only to its own innovation and developments in world energy prices. Inflation contemporaneously responds to GDP growth (as the economy overheats or slows down), world oil prices and its own shock (cost-push shock). Monetary policy variables react to all non-policy variables in the current period.

We use real oil price – nominal Brent spot price deflated by the U.S. CPI – as a benchmark measure of the oil market indicator, but we also experiment with nominal oil price inflation and Hamilton's net oil price increase as alternative measures. The net oil price change is computed as a positive increase in the nominal oil price from the highest value in the previous 4 quarters.

The quarterly model with an international oil market block is estimated with an additional set of variables from the world oil market (as shown in equation (2.7) below). In particular, world oil production growth, global real economic activity, and the real price of oil are included in the SVAR model prior to the domestic block in the same order. The structural shocks affecting the variables in the international oil market – $\{u_t^{\Delta Q^{Oil}}, u_t^{GEA}, u_t^{P^{Oil}}\}$ – are identified as the *oil supply shock*, *global economic activity shock*, and *oil-market-specific demand shock* respectively. This is the terminology used by Kilian (2009a). Note that all these shocks (including the global economic activity shock) are fundamental shocks that drive the international price of oil and are considered different types of oil shocks. We use this terminology in this and the next chapter.

$$\begin{pmatrix} \epsilon_t^1 \\ \epsilon_t^2 \\ \epsilon_t^3 \\ \epsilon_t^4 \\ \epsilon_t^5 \\ \epsilon_t^6 \\ \epsilon_t^7 \end{pmatrix} = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{2,1} & a_{2,2} & 0 & 0 & 0 & 0 & 0 \\ a_{3,1} & a_{3,2} & a_{3,3} & 0 & 0 & 0 & 0 \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} & 0 & 0 & 0 \\ a_{5,1} & a_{5,2} & a_{5,3} & a_{5,4} & a_{5,5} & 0 & 0 \\ a_{6,1} & a_{6,2} & a_{6,3} & a_{6,4} & a_{6,5} & a_{6,6} & 0 \\ a_{7,1} & a_{7,2} & a_{7,3} & a_{7,4} & a_{7,5} & a_{7,6} & a_{7,7} \end{pmatrix} \begin{pmatrix} u_t^{\Delta Q^{Oil}} \\ u_t^{GEA} \\ u_t^{P^{Oil}} \\ u_t^{GDP} \\ u_t^{CPI} \\ u_t^{M1} \\ u_t^{ER} \end{pmatrix} \tag{2.7}$$

The Georgian sample starts in 2000Q2 and ends in 2013Q2, while the Armenia sample is slightly shorter, ending in 2012Q4. The available sample is rather short and large lag length results in unstable estimates as each additional lag requires 25 additional parameters to be estimated. The usual procedure is to select the number of lags based on standard information criteria (AIC and SBC) and an LR test. Given that the size of the sample is relatively small, we used the information criteria as a guide. For most of the specifications, a lag length of 8 quarters was not feasible.

The lag length of 6 produced similar but less significant results to those reported. Thus, we opted to report the results for the lag length of 4 and in some cases 3 lags depending on the information criteria.

The model is quarterly, compared to Killian's original (2009a) monthly model of the international oil market. As mentioned above, a measure of value added output is not available at monthly frequency for the countries under study. Given the importance of this variable in theory as well as practice, we estimate a quarterly model with the international oil market variables aggregated into quarterly frequency. An alternative is to estimate a monthly world oil market model and use the identified and estimated shocks in a quarterly distributed lag (DL) model as in Kilian (2009a). However, this creates an issue with generated regressors that cannot be easily dealt with due to mixed frequencies.

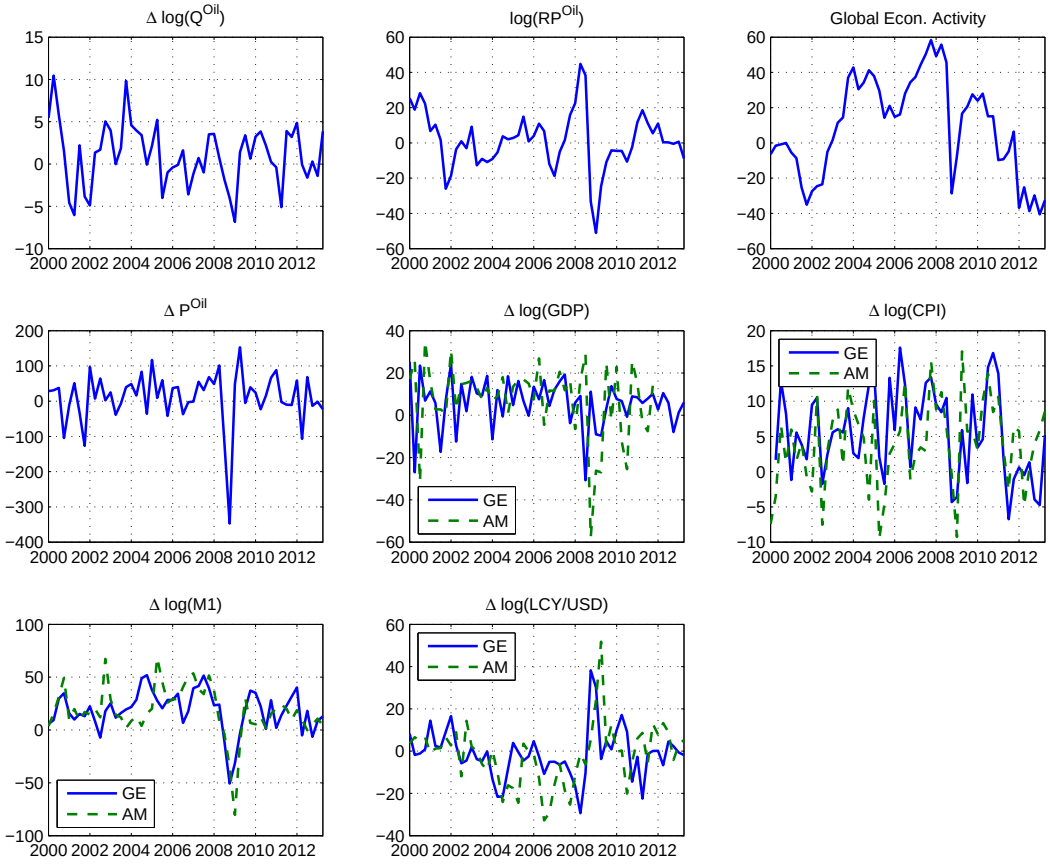

Figure 2.1: Variables in SVAR. Growth and inflation rates are in percent, QoQ, @ar, logarithmic approx. Variables: $\Delta log(Q^{Oil})$ Growth in real oil production; Global Econ. Activity – Kilian's measure of global economic activity based on international freight rates; $Log(RP^{Oil})$ U.S. CPI deflated Brent spot crude oil price; $\Delta log(P^{Oil})$ Brent nominal spot crude oil price inflation; $\Delta log(GDP)$ Real GDP growth; $\Delta log(CPI)$ CPI inflation; $\Delta log(M1)$ Monetary aggregate – M1 growth; $\Delta log(ER)$ Nominal bilateral exchange rate depreciation, local currency per USD.

Figure 2.1 displays the evolution of the variables for Georgia and Armenia used for the estimation of the quarterly model. All of the variables were seasonally

adjusted (if required) using the X13-ARIMA-SEATS seasonal adjustment procedure and tested for the presence of unit root. A few observations are worth mentioning. First, most of the variables display significant and sudden change at the onset of the world financial crisis following the abrupt slowdown of global economic activity (especially the nominal price of oil). We do control for global economic activity but do not account for the state of financial sector, thus, the results should be interpreted cautiously taking this fact into consideration. Second, given a sizable shadow economy of the countries under study, the results reflect the effects of the shocks on at least imperfectly measured output series. Third, the variables are rather volatile. GDP and inflation display significant swings. Finally, there appears to be significant comovement between the inflation processes in the two countries, indicating some common external factors. Such a comovement is less visible between the other macroeconomic aggregates.[8]

4 Results and Discussion

First, we present key regularities observed in the data on the structure of the energy flows, the role of global real economic activity, and the channels of transmission. The results from the SVAR model discussed above are shown afterwards.

4.1 Energy Flows

As a starting point, it is informative to look at the structure of energy flows. Figures 2.2 and 2.3 show the decomposition of energy flows based on sources and final uses in Georgia and Armenia respectively for 2011.

A few interesting findings emerge. First, natural gas imports account for a large portion of produced and imported energy. The share is much larger for Armenia amounting to 56.1%, compared to 40.5% share in Georgia. In general, the pricing of natural gas in the region is based on long-term, backward-looking contracts with the base price indexed to crude oil price or the price of refined oil products (Stern, 2014). Thus, unlike areas with hub-based pricing, global oil price shifts are likely to directly influence Armenia and Georgia with some delay through the gas sector. Due to this, the effect of oil shocks is expected to be larger compared to effects in developed economies. However, imports and pricing of natural gas in the region is influenced by political processes (Svoboda, 2011). Arguably at least some of the natural gas supplied by Russia to Georgia and Armenia in the late 1990's and the first half of 2000's was available at concessionary prices. Such pricing would

[8] All of the variables used are available from public sources, and may be obtained from the author upon request.

lead to a weaker effect of oil price shocks, attenuating some of the impact through subsititution between alternative sources of energy. Interestingly, we do observe that Armenia, a strategic partner of Russian Federation, has a much higher share of natural gas. Nevertheless, Gazprom's policy to transition from concessionary prices to "European" level for CIS customers as well as alternative supply sources available for Georgia after 2007 is likely to once again amplify the effects of oil shocks. Additionally, transit services for Azerbaijani oil and gas through the Baku-Tbilisi-Ceyhan oil pipeline and the South Caucasus gas pipeline as well as for the natural gas flowing to Armenia generate significant revenues for Georgia (amounting to 1.6% of GDP in 2012). This may soften or amplify the effects of oil price shocks depending on how the changing prices affect the transit revenues. The bottom line is that the relationship between the oil and natural gas sectors is complex, and the joint modeling of the two sectors would likely improve the performance of the model. However, due to data limitations on the gas sector and the complexity of the relationship between the two sectors, we concentrate on the effects of oil shocks only.

A second interesting finding is that both countries have a significant hydro sector (at 18.2% and 7.2% of total energy imports and production for Georgia and Armenia respectively in 2011). However, the hydro sector is seasonal and is available more abundantly in warmer periods. Additionally, Armenia has large nuclear production (22.3%). These factors reduce the impact of oil price fluctitions over time as new hydro resources are developed.

Third, a large part of oil products imports (28.1%) are mostly used by the transportation sector in Georgia. In contrast, Armenia utilizes a much smaller share of imported oil products in the transportation sector, relying mostly on natural gas. Finally, imported oil products are small compared to electricity and natural gas in industry consumption for both countries.

4.2 Channels

Before we look at the data relevant to various transmission channels of oil price shocks, it would be useful to identify the oil shock episodes for the period of study to better visualize the dynamics of the key variables during these episodes. The top panel of Figure 2.4 shows the evolution of Brent spot oil prices from 2000Q1 to 2013Q3 and Hamilton's measure of oil market indicator. Oil price shocks episodes are highlighted in gray and are chosen based on two criteria. First, a period leading to at least a 40% increase pick in year-on-year quarterly oil price inflation. Second, by significant spikes in Hamilton's net oil shock measure. We can see that the two measures mostly agree. An exception is a small spike in net oil price change in

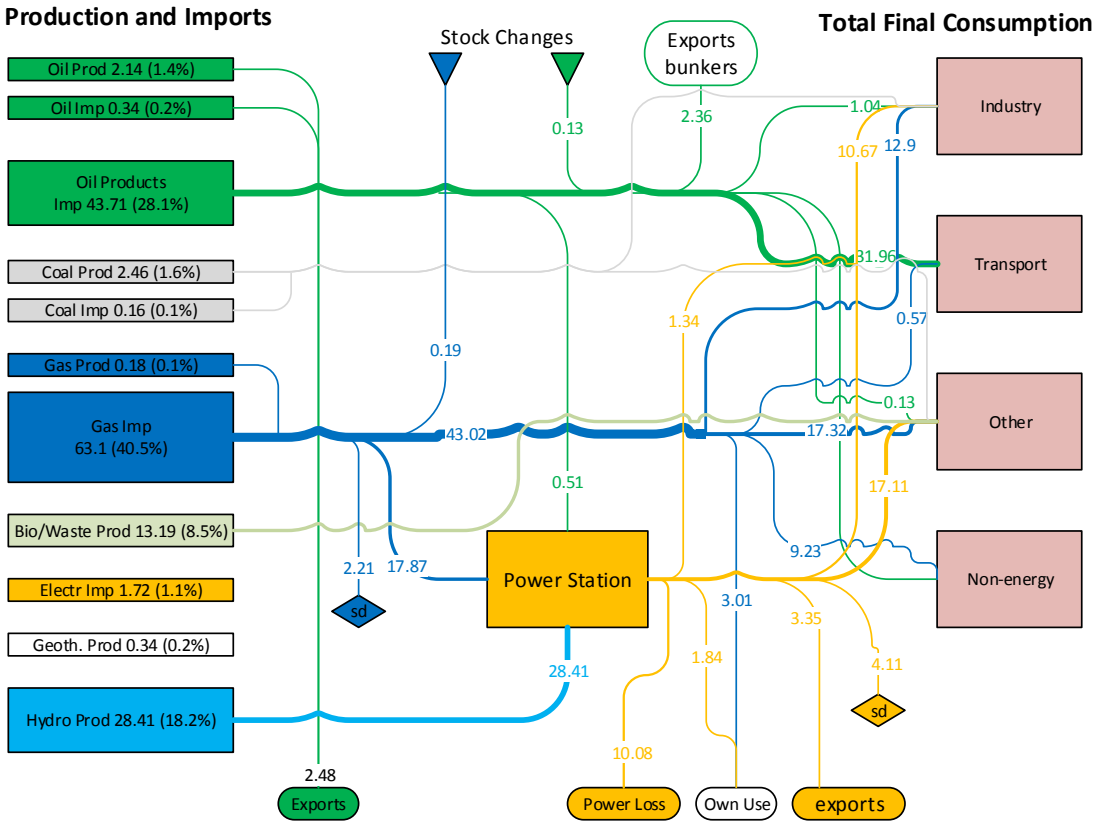

Figure 2.2: Georgia: Structure of Energy Flows. Total 2011 energy production and imports – 155.8 PJ. (69.75 thousand boe/d) Total Consumption – 127.1 PJ (56.90 thousand bbl/d). Percentages in parenthesis are relative to total energy production and imports. Source: IEA.

early 2006 that was quickly reversed. The lower panel shows the evolution of the three different shock types (residuals) from a monthly model of the international oil market similar to that of Kilian (2009a).[9] Note that, according to the model, different types of shocks are responsible for different oil shock episodes. Moreover, shocks to global economic activity seem to be important drivers of the world oil prices.

Inflation Channel

Inflation in Armenia and Georgia is rather volatile, and highly influenced by external factors. As illustrated in Figures 2.5 and 2.6, food and energy products are the

[9]There are some differences in our specification compared to the benchmark paper. In particular, we use Brent spot oil price instead of prices based on the refiner acquisition cost of imported crude oil that is a relevant variable for the U.S. We also use additional observation including those from and after the global financial crisis of 2007-2008, but our sample starts in 1979M1 instead of early 1970's as we do not have access to earlier observations of oil price series. Nevertheless, the latter is not an issue since we are interested in the effects of oil shocks starting in 2000s. Finally, we removed a HP trend from the real oil price series since we were not able to reject the null hypothesis of unit root in the unfiltered series. This does not significantly affect our results.

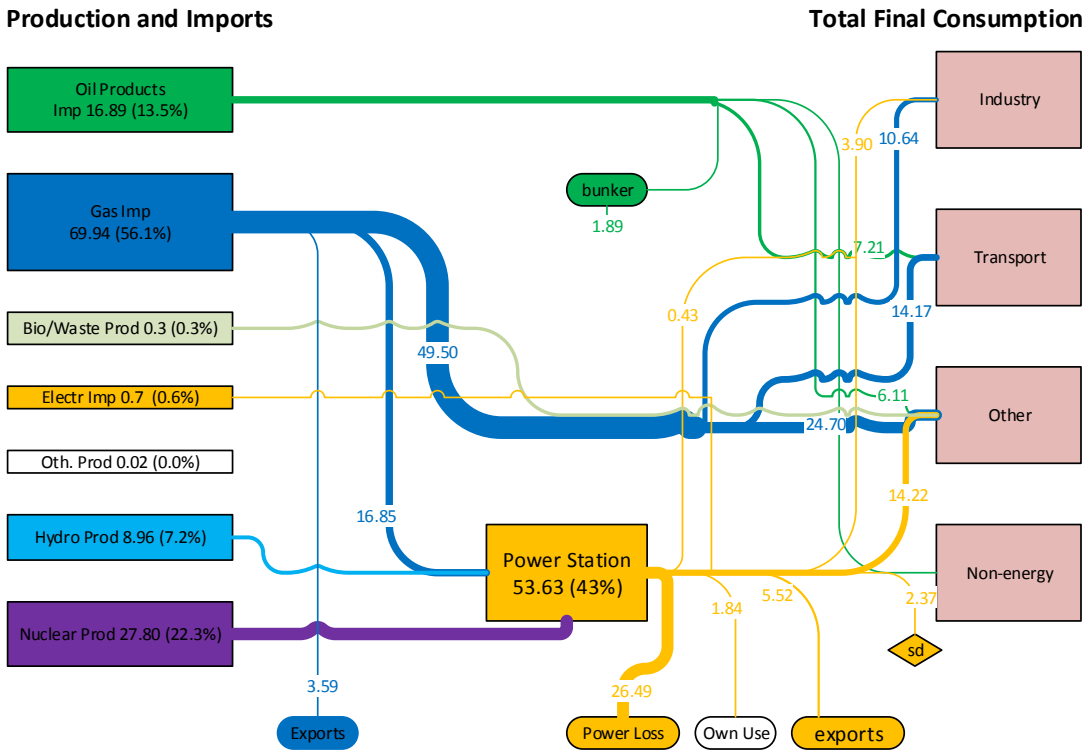

Figure 2.3: Armenia: Structure of Energy Flows. Total 2011 energy production and imports – 124.7 PJ. (55.84.75 thousand boe/d) Total Consumption – 83.8 PJ (37.59 thousand bbl/d). Percentages in parenthesis are relative to total energy production and imports. Source: IEA.

largest contributors to headline CPI inflation.[10] In Georgia, energy products enter 2 components of headline CPI index: (1) Housing, water, electricity, gas and other fuels component – 8.8%; (2) Transport component – 12.7%. The latter also includes gasoline, diesel, and liquid gas prices.

Figure 2.7 shows the dynamics of Georgian fuel prices together with the world fuel price index and the Brent crude oil price. There is clear evidence of pass-through of world fuel prices to domestic gasoline and diesel prices. If we assume complete pass-through and 20.5% upper bound for fuel share in CPI (based on the CPI components that contain fuel), then the direct effect for Georgia (excluding indirect effect from food and other components) is about 2.1% increase in inflation in response to a 10% increase in the price of crude oil. Interestingly, we do observe some spikes in inflation during the oil shock episodes, but we also observe such spikes during the period of increased world economic activity for both countries under study.

While the shares of components change over time and the share of food has been declining, this category, which includes food, beverages, alcohol and tobacco, still

[10] Note that the component shares for Armanian CPI, diplayed in Figure 2.6, are averages estimated over the whole sample. Based on the evolution of individual series we can see the negative contribution of the transportation component is due to reduced share rather than large decline in the component *per se*.

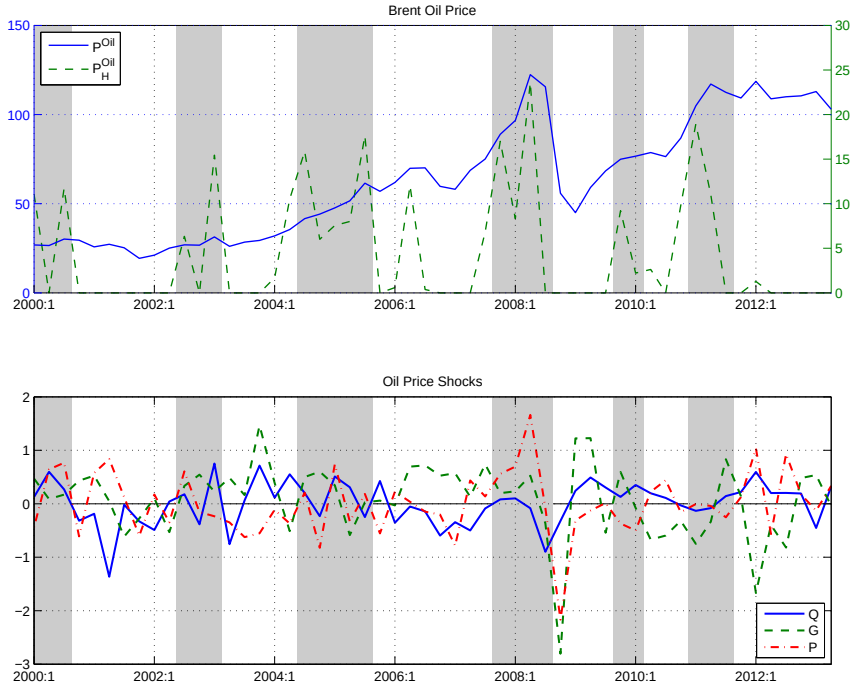

Figure 2.4: Oil Price and Oil Shocks. Top panel: Brent Crude oil price and Hamilton's net oil price change. Bottom panel: Oil shocks identified in the model of the international oil market similar to the those summarized in equation (2.7). The model is estimated at monthly frequency using the variables from international oil market only. Source: World Bank, Kilian (2009a), our calculation.

has a relatively large share compared to developed economies. For example, the share of food items constituted 36.1% in Georgia in 2013 and 53.5% in Armenia in 2012, compared to 14.6% in U.S. CPI in 2013.

Given the coupling of energy and food commodity prices, it may be argued that at least some of the increase in crude oil prices will pass-through to commodity food prices and retail food prices. Moreover, Baumeister and Kilian (2013) argue that, much like the crude oil prices, food prices are also subject to shocks due to fluctuation in global real economic activity. This may be much more relevant for developing countries, where the share of food items in the CPI is larger and possibly the pass-through to retail food prices is stronger.

The Demand Channel

Aggregate demand is considered to be an important part of the transmission mechanism of oil price shocks for developed economies. As shown in Figure 2.8, the real GDP growth is accelerating in some oil shock episodes, while it is declining in others. Unfortunately, real GDP components by final consumption are not available for Armenia and Georgia, but we can still examine CPI deflated nominal private consumption. In general, we do not observe any clear pattern in the relationship between oil prices and the real GDP and real consumption growth. However, real

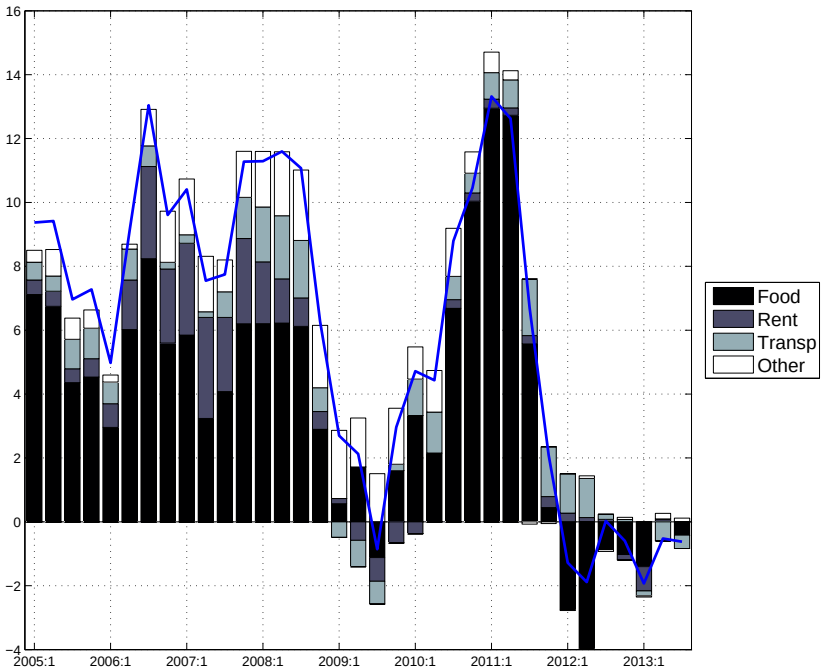

Figure 2.5: Decomposition of Inflation in Georgia. %, YoY, constant average weights. Source: GeoStat – national statistical agency; NBG – National Bank of Georgia.

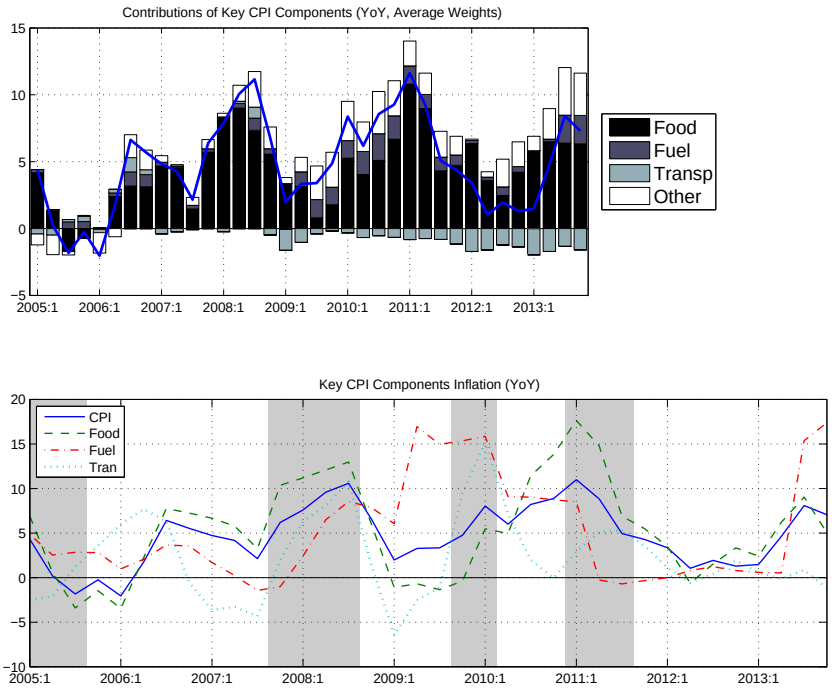

Figure 2.6: Decomposition of Inflation in Armenia. %, YoY, constant average weights. Source: National Statistical Service of the Republic of Armenia.

consumption growth seems to spike during periods of intensified global economic activity. Decomposition of the real GDP by industries does not reveal any special influence of oil shocks on different industries (figure is not shown to conserve space).

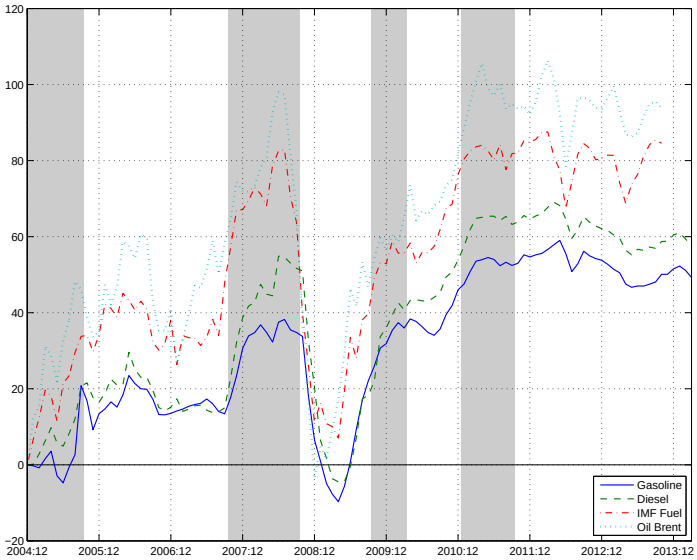

Figure 2.7: Georgia: Transmission of International Fuel Prices to Local Fuel Prices (100*log). All prices in GEL. Variables: Gasoline – gasoline price index; Diesel – diesel price; IMF Fuel – IMF fuel price index; Oil Brent – Brent spot oil price. Source: GeoStat, IMF, WB.

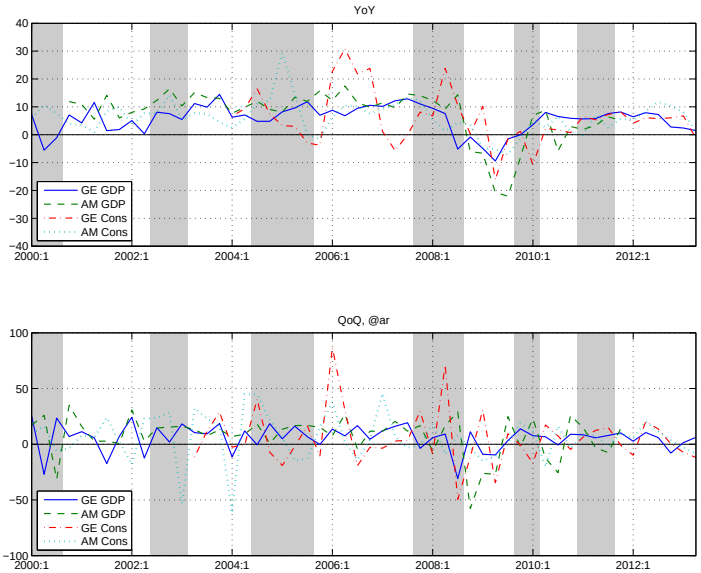

Figure 2.8: Growth Real GDP, Real Consumption. Source: GeoStat, Cental Bank of Armenia.

Monetary Policy

Monetary frameworks in Georgia and Armenia have been gradually evolving from a monetary targeting regime to an inflation targeting regime starting around 2006. Nowadays short-term interbank rates serve as the operational targets and are managed to remain within a specific band of the central bank rate. Inflation is targeted at 6% medium-term target with a long-term goal of 3% in Georgia.[11] The character-

[11]Discussion and examples are mostly focused on Georgia in this section to save space, but similar arguments hold for Armenia.

istics of the monetary policy are consistent with the 3 criteria for inflation targeting suggested by Svensson (1999).

However, the interest rate channel is relatively weak, as the long-term interest rates (and loan volume) are not responsive to policy changes. The weakness stems from high dollarization of loans and deposits at about 60%, underdeveloped financial markets, possibly less competetive banking sector, and low monetary policy credibility associated with the hyperinflation episode of the mid 1990's. This is illustrated for Georgia in Figure 2.9, that shows that though the central bank does influence the interbank short-term rate, the rates on longer-term local currency loans and deposits seem to evolve autonomously. Similarly, if we plot the evolution of the monetary aggregates, we do not observe clear comovement between them and the long-term interest rates (not shown to save space).

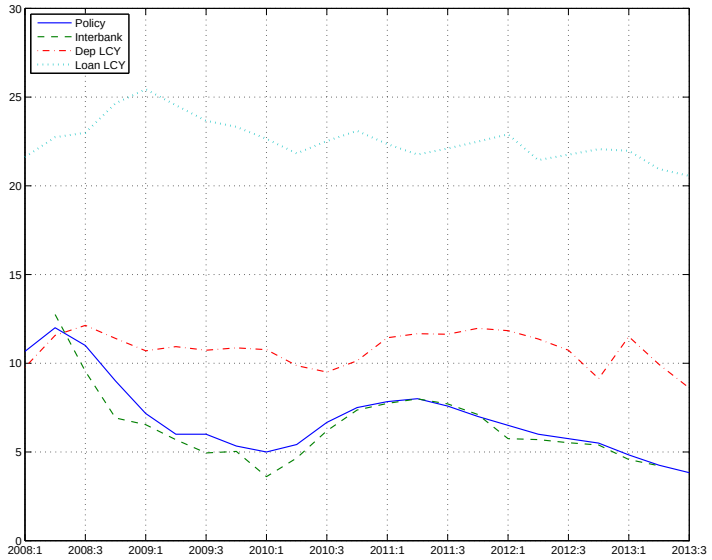

Figure 2.9: Georgia: Policy, Interbank, Loan and Deposit Rates. % p.a.

The exchange rate is a managed float subject to occasional interventions. For example, the USD/GEL exchange rate remained within 1% for an extended period of time in the second part of 2012 and 2013 (International Monetary Fund, 2013). This opens up a possiblity that the central bank may interfere in the exchange market to counteract the inflation pressures caused by higher energy prices. However, this option is arguably rather costly.

If we look at the growth rates of the monetary aggregates and in particular the monetary base in Georgia in Figure 2.10, we will see that every price shock episode is followed by reduced growth in the monetary base (as well as the monetary aggregate – M1). It may seem that the central bank is tightening its policy stance in response to (and after) oil price shocks.

However, the shock episodes are also associated with increased global economic

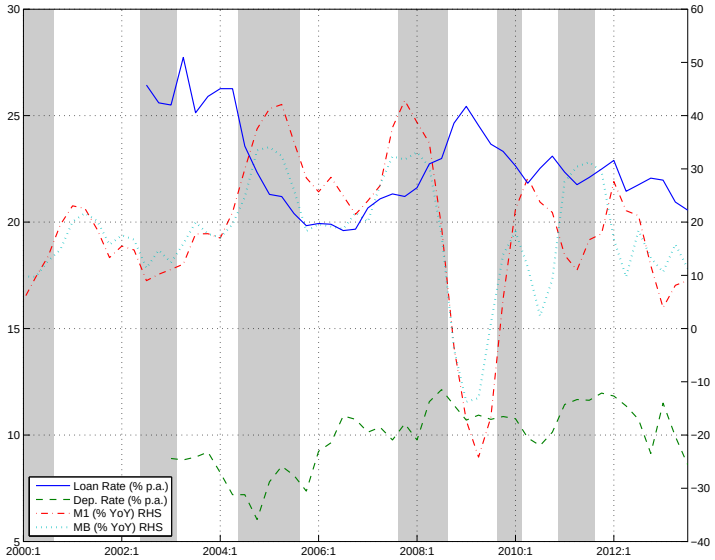

Figure 2.10: Georgia: Growth of Monetary Aggregates and Interest Rates. % p.a. Source: NBG,Kilian (2009a)).

activity and overheating of the economy after the inflow of foreign finances. Figure 2.11 illustrates the point. The top panel shows the evolution of the monetary aggregates and a measure of global real activity index compiled by Kilian (2009a) based on international freight rates. The bottom panel depicts the components of the financial accounts of the balance of payments for Georgia. We can see that the periods of high global real activity are associated with the accelerated inflow of foreign finances.

Despite the weak interest rate channel, systematic monetary policy may still be an important factor in oil price shock transmission. Though it is possible to address this question in the SVAR framework used in this paper, it is preferable to study the issue in a more structural – DSGE – setup, which is beyond the scope of this chapter.

Fiscal Channel

The effects of energy price hikes may be countered by fiscal policies that may at least temporarily delay price increases through the use of subsidies. In fact, there is evidence that the Georgian government has used subsidies to alleviate the effects of increasing natural gas tariff (International Monetary Fund, 2006, p. 13). However, as discussed earlier, the fuel market (i.e., the market of crude oil products, mainly gasoline and diesel) is less regulated, and the available data do not indicate a systematic increase in government spending during the oil shock periods (c.f. Figure 2.12). Moreover, limitation of the data make analysis of this channel unfeasible in the context of this paper. A DGSE model is better suited for such analysis and is an

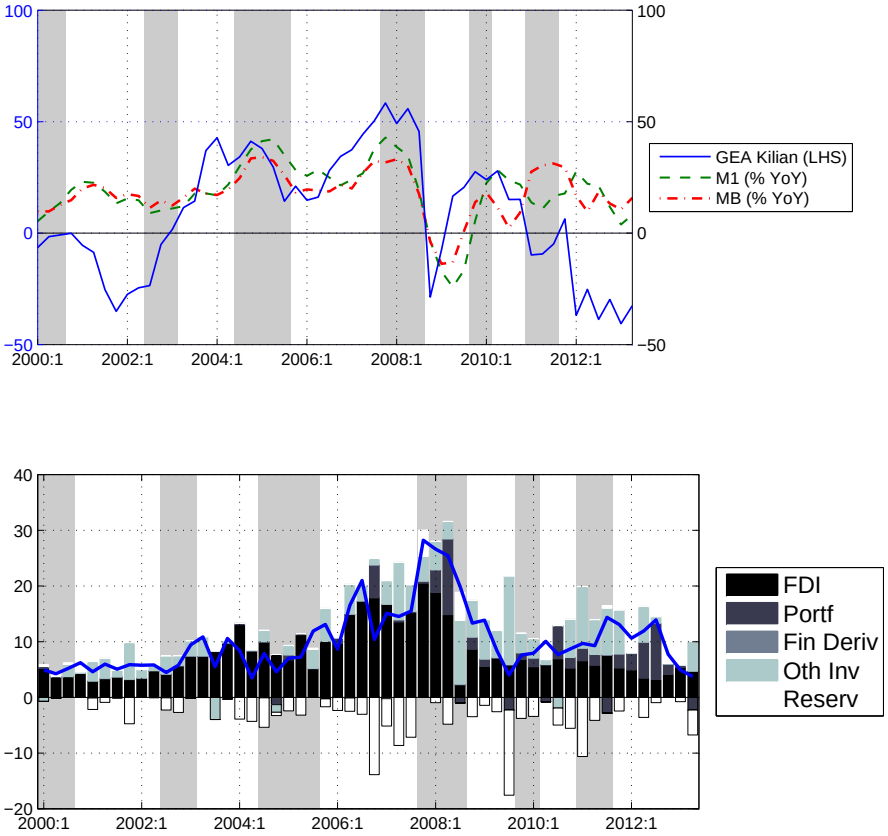

Figure 2.11: Georgia: Growth of Monetary Aggregates, Global Economic Activity and Balance of Payments. % p.a. Source: NBG, Kilian (2009a)

interesting topic for further research as this channel is not explored for oil-importing, developing economies.

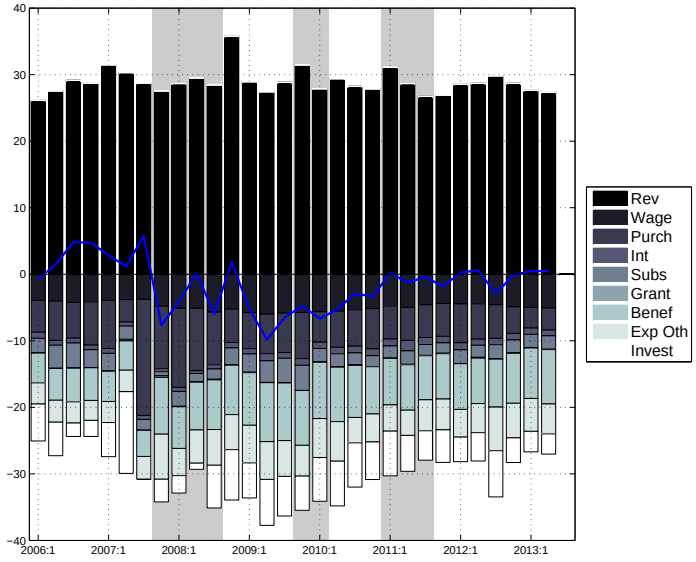

Figure 2.12: Georgian Budget Decomposition. % of GDP. Source: Ministry of Finance of Georgia

4.3 SVAR Results

We estimate two separate quarterly models described in the methodology section for each of the countries. The benchmark specification includes only a single measure of oil market indicator in the foreign block, and the extended specification includes a full model of international oil market outlined in the methodology section. We use a U.S. CPI deflated Brent crude oil price as an oil market indicator in the benchmark specification. We also experiment with nominal Brent oil price growth and Hamilton's measure of net oil price change. These measures produce similar results to the real oil price measure but with less pronounced effect on the GDP. In order to save the space, we do not present these results here and concentrate on the real oil price. Instead, it is interesting to compare the effects of each type of oil shocks suggested by Kilian (2009a) to the benchmark case based on real oil price that may be thought of as their combination.

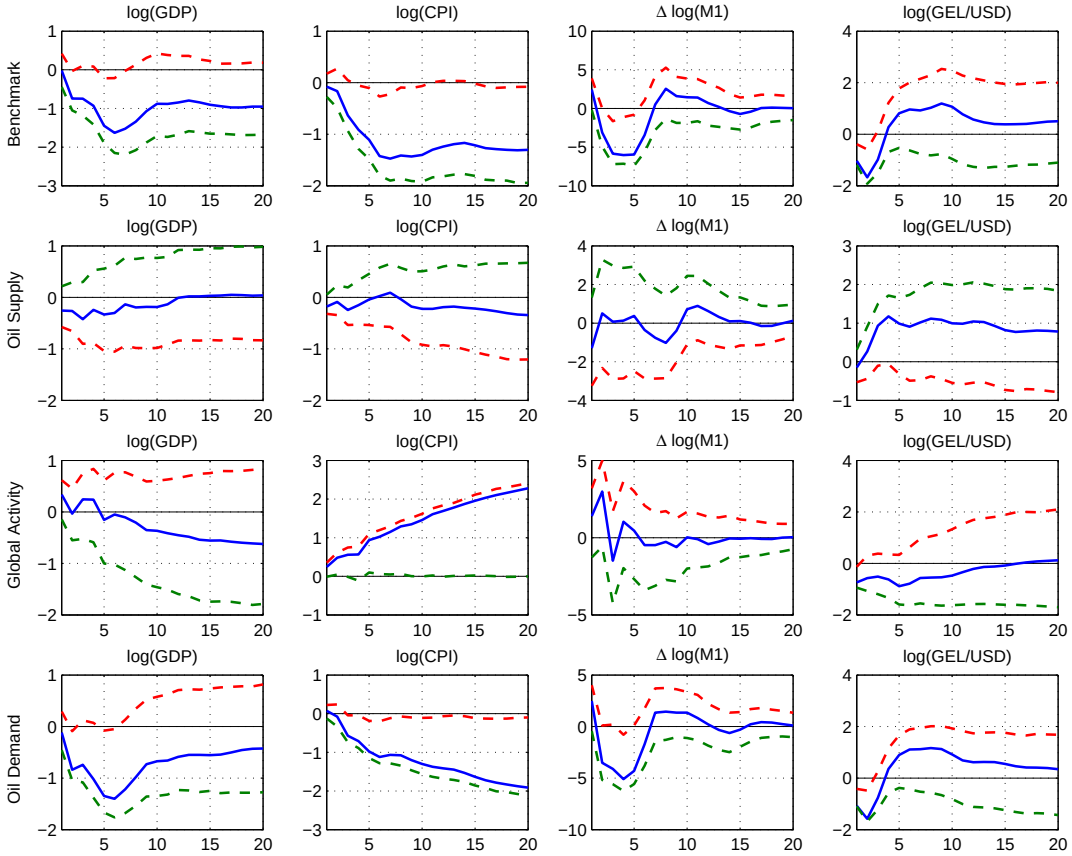

Figure 2.13: Georgia: Impulse Responses to 1 SD Oil Shocks. Variables measured in logs and percentages. Each row represents a model with specific shock measure. Row 1: Log real oil price is used as the world oil market state indicator in the benchmark model. Row 2: Oil supply (disruption) shock. Row 3: Shock based on increased global real activity; Row 4: Shock stemming from oil-market-specific demand innovations. Rows 2 to 4 are from the extended model with international oil market. 90% wild bootstrap confidence intervals. Responses are accumulated for the level of the variables.

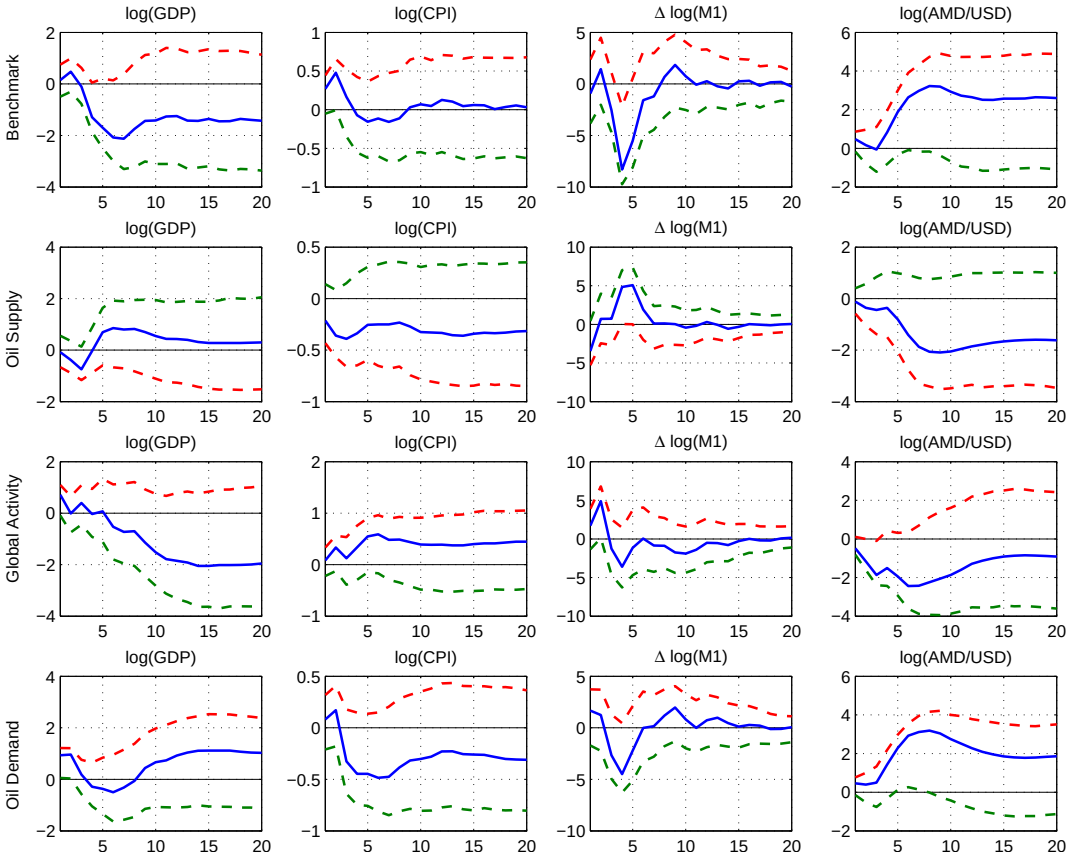

Figure 2.14: Armenia: Impulse Responses to 1 SD Oil Shocks. Variables measured in logs and percentages. Each row represents a model with specific shock measure. Row 1: Log real oil price is used as the world oil market state indicator in the benchmark model. Row 2: Oil supply (disruption) shock. Row 3: Shock based on increased global real activity; Row 4: Shock stemming from oil-market-specific demand innovations. Rows 2 to 4 are from the extended model with international oil market. 90% wild bootstrap confidence intervals. Responses are accumulated for the level of the variables.

Figures 2.13 and 2.14 display the reaction of macroeconomic variables of interest to 1 SD shock of each type. The first row represents the benchmark model, where we do not decompose the shock, while rows 2 to 4 represent a model with international oil market.

The *benchmark* specification produces impulse responses that are difficult to interpret for Georgia in a standard setting as they imply that an abrupt oil price shock is followed by persistent and significant decrease in GDP and CPI level. Though this is consistent with a strong demand channel, it does not fit in a conventional theoretical framework with emphasis on the inflation channel. The benchmark results for Armenia are more in line with the traditional effect, but the responses are only marginally significant. Monetary policy displays a delayed hump-shaped tightening in both countries while the exchange rate appreciates in the short run in Georgia only. Some of the responses are difficult to explain within the framework of conventional theories on oil shocks.

The *oil supply shock* shown in the second row of Figures 2.13 and 2.14 does not lead to sizable and significant effects on output or CPI responses in Georgia or Armenia. Monetary policy and exchange rate responses include 0 in a 90% confidence interval. This is consistent with the literature on developed economies.

Interestingly, the *shock induced by accelerating global economy* results in no significant effect on GDP level, but a significant CPI increase in Georgia; CPI increases in Armenia as well, but less significantly. The exchange rate appreciates temporarily for both countries. This is partially consistent with the following scenario: Stronger global markets lead to higher oil prices, but also have strong impact on local macroeconomic variables possibly through the higher inflow of FDI, remittances, exports of tourist services, etc. Higher inflow results in accelerating domestic demand, and hence higher inflation. An appreciating exchange rate is an artifact of the increased demand for the local currency due to the inflow of funds.

Since we do not control for the effects of imported food prices, at least part of the CPI increase may be due to increasing international food prices, that coincide with the increase in crude oil price due to a common driving factor.

The *oil-market-specific demand shock* captures all effects on the real price of oil not due to supply disruption or global economic conditions. Kilian (2009a) argues that this residual shock mostly captures the precautionary demand sentiments of the oil market. This shock has strong negative impact on GDP and CPI inflation in Georgia. The effect on GDP is similar in Armenia but not as significant. The shock is followed by temporary policy tightening. The currency appreciates in the short run in Georgia and returns to longer-term depreciation. The exchange rate depreciates in Armenia in the long term, but this effect is only marginally significant. The reaction of the policy variable and the exchange rate may be puzzling but is consistent with tightening of policy by the monetary authorities to prevent the currency from depreciation due to increasing oil prices as well as inflation expectations, given a sizable increase in world crude oil prices.

The reaction of the variables to the three types of shocks shown in Figure 2.13 is consistent with a strong demand channel that stipulates that the rising oil prices and rising prices on oil products reduce the aggregate demand (also consistent with strong decline in real GDP), that in turn results in declining inflation. The decline in aggregate demand is possibly not strong enough to exert downward pressures on CPI in the case of oil supply shocks, hence the different reaction of inflation compared to oil-market-specific demand.

In a series of papers, Kilian emphasizes the importance of the demand channel for the United States and other developed economies (Kilian, 2008b, p. 881). Aastveit (2013) studies the impact of the three types of Kilian's oil shocks on the U.S. economy using the FAVAR framework. One of his benchmark (non-FAVAR)

specifications is similar to the specification used in this paper. First, similar to our findings for Georgia and Armenia, the responses to the oil supply shock are small and insignificant in the U.S. Second, in line with our results for the developing economies in this study, global demand shocks increase real oil price and various price measures and have significant negative effect on employment and output with a delay (after two years) in the U.S. Monetary policy is tightened after the global demand shock in the U.S. Finally, oil-specific demand shock increases real oil prices and various price measures and has a negative effect on production and unemployment in the United States – this is consistent with increased CPI inflation and a negative effect on GDP. In contrast, we find negative effect on CPI inflation in our sample of countries. Nevertheless, despite these differences and the differences in the level of economic development of the two countries, it is interesting that the estimated dynamic responses of the key variables are broadly consistent and fit the same conceptual framework.

The most important takeaway point of the decomposition exercise is that different types of oil shocks have different effects on the macroeconomic variables of the countries that we study. Specific responses of the variables to the different types of oil shocks depend on the choice of the specification and the variables used in the model. For instance, we looked at GDP deflator, reserve money, and nominal effective exchange rates as alternative measures of the concepts used in the model, and though there are some differences from the benchmark specification, the main findings do not changed.

Given the relatively high share of food component in headline CPI for developing economies (as shown in Figure 2.5 for Georgia), we expect a relatively higher share of increased world food commodity prices to pass through to domestic retail food prices. As discussed above, there is evidence that some of the increases in world oil prices are likely to be transmitted to increased food prices and that the world food commodity prices are also subject to the shocks stemming from world real activity fluctuations (Baumeister and Kilian, 2013). Thus, oil price jumps from stronger world economic activity will have a larger effect on inflation for developed countries. In fact, we do observe a significant increase in the CPI variable in the SVAR model for Georgia (and a marginally insignificant increase in the CPI for Armenia). This effect may come from increased oil prices or directly as a result of accelerating world economy. Though we do not include world food prices in the model and cannot distinguish between these two effects in this paper, it seems to be important to model oil and food prices jointly in a more structural setup.

The impulse response of the monetary policy variable indicates that policymakers respond to different types of oil shocks differently. We can see that the policy is tightened in response to oil-market-specific demand shocks in Georgia and Armenia.

This result is only marginally significant in Armenia. We also observe marginally significant monetary policy easing after an oil supply shock in Armenia. The reaction to other types of shocks is not significant. As discussed earlier, the interest rate channel of the monetary policy is considered weak due to credibility issues of the monetary authority and significant partial dollarization. Nevertheless, we see evidence that the central banks do respond to some shocks and the responses are different based on the types of shocks.

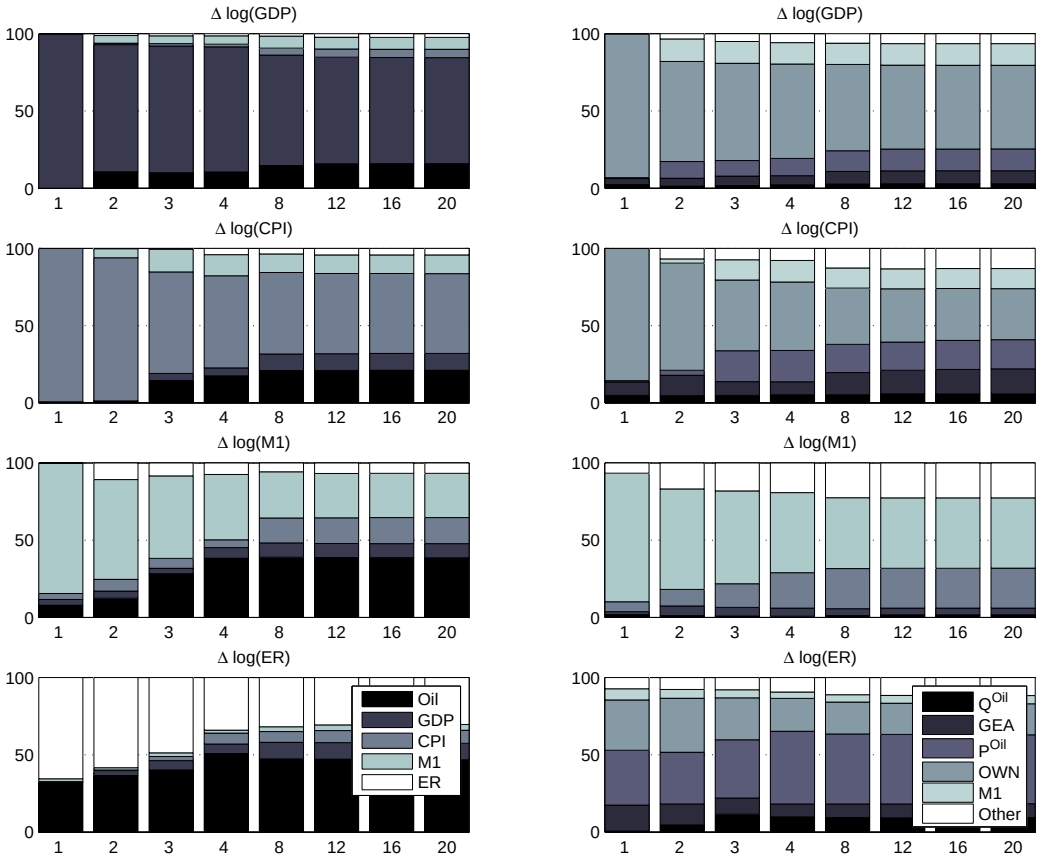

Figure 2.15: Georgia: Forecast error variance decomposition. Left column – baseline model. Right column – model with world oil market. Variables defined in Figure 2.1.

The results of forecast error variance decomposition (FEVD) are presented in Figures 2.15 and 2.16 for each of the estimated models. The forecast horizon varies from one quarter to 5 years, after which the shares converge to long-term values. The left columns display the FEVD for the benchmark model, while the right column shows the FEVD for the model with different types of oil shocks. Shocks explain relatively less variation for the output and CPI compared to the monetary aggregate and the exchange rate in the benchmark model. Note that, consistent with relatively less exposure to the oil price shock as seen in the energy flows chart, the oil shocks explain significantly more variation in inflation, M1 and exchange rate in Georgia as compared to Armenia. This is the case for both specifications.

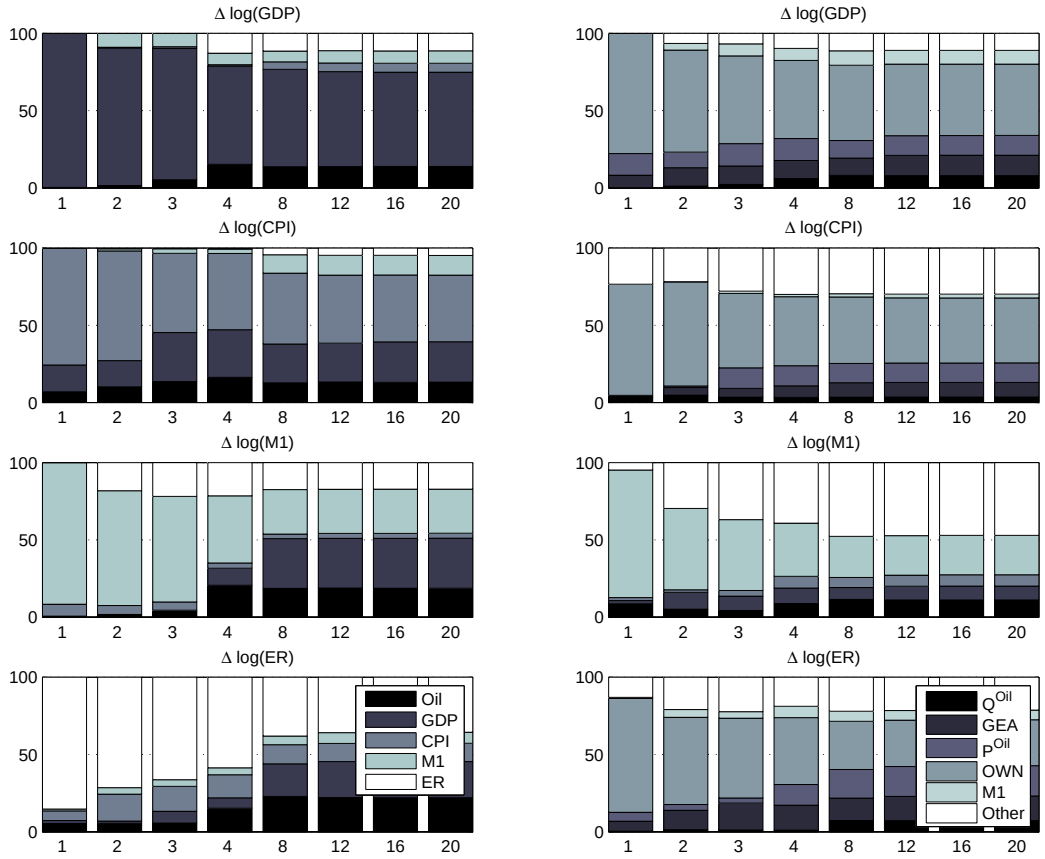

Figure 2.16: Armenia: Forecast error variance decomposition. Left column – baseline model. Right column – model with world oil market. Variables defined in Figure 2.1.

In general, the magnitude of the share of the oil shock in the benchmark model is consistent with that in the model augmented with detailed international oil market structure. If we concentrate on the three types of the shocks from the world oil market model, we see the following: First, different types of shocks have different impact on the forecast variance of the macroeconomic variables. Second, oil supply shocks play a relatively minor role, consistent with the identified impulse responses. Third, a relatively large share of the variation in the exchange rate (and less so of M1) is explained by oil shocks, with the oil-market-specific shock having the largest share.

We see the following as the main contribution of this paper. The results of the estimated models (and the analysis of key macroeconomic indicators for Georgia and Armenia) suggest that it is important to account for the original source of an oil price shock in order to understand its impact on the economy. Though one might argue that small open economies take world oil prices as a given and are exogenous to the dynamics of local macroeconomic variables, the "open" part in the definition makes the oil prices endogenous, as the macroeconomic variables are affected by the same global factors that shape the world oil prices.

5 Conclusion

This project studies the impact of oil price fluctuations on oil-importing developing economies, concentrating on Armenia and Georgia. Analysis of the effect of oil shocks is based on three main factors – the sources of oil price shocks, the transmission mechanism through which the shocks propagate, and the structure of energy flows that affect the transmission. The emphasis is on specificities of small, open, oil-importing, developing economies. Our results are based on the detailed analysis of the dynamics of key energy and macroeconomic variables as well as the insights from a SVAR model.

The estimated SVAR model with different types of oil shocks confirms the importance of accounting for the endogeneity of oil prices to global economic activity and the underlying source of an increase. The effect of oil price swings is different depending on the type of the oil shock. Modeling oil shock as an innovation to the oil price indicator or its nonlinear transformation is a shortcut, but it only shows the combined effect of different types of oil shocks at best.

Using methodology developed by Kilian (2009a), we identify and compare the effects of different types of fundamental structural oil shocks on the economies under study. We find that oil supply shocks lead to small and insignificant effects on all of the variables included in the model, while the oil price shocks due to increased global economic activity and oil-market-specific demand shifts have strong and mostly significant effects.

The identified impulse responses show that oil-market-specific demand shocks, which are considered important drivers of world oil prices, do not lead to higher inflation and in some cases even reduce the output. More specifically, we observe significant negative effect on CPI and GDP in Georgia, and negative but insignificant effect on CPI in Armenia. This is consistent with a strong demand channel.

It is well known that the contribution of the food component to CPI inflation is much larger for developing countries as the weight of this component is relatively high in consumer expenditures. We illustrate this for Georgia, but the same is true for Armenia, which has an even higher share of food in its headline CPI. It is well known that the food prices and energy prices are connected. However, Baumeister and Kilian (2013) argue that world food commodity prices are also subject to shocks stemming from world economic activity fluctuations. Thus, increased global economic activity may simultaneously affect oil and food commodity prices. Therefore, oil shocks due to accelerating world economic activity will have stronger effect on inflation in developed economies. In fact, we have some evidence for this in Georgia, but the results are marginally insignificant for Armenia.

A priori we did not expect a strong role of monetary policy in the transmission of

oil shocks since the interest rate channel of the monetary policy appears to be weak. As discussed above, it is difficult to gauge the role of systematic monetary policy from either the SVAR estimates or a simple look at the dynamics of the relevant variables. Nevertheless, we can still see if monetary policy responds to different types of oil shocks based on the identified impulse responses. We found that the policy is tightened in response to oil-market-specific demand shocks in Georgia and Armenia. This result is only marginally significant in Armenia. We also observe marginally significant monetary policy easing after a oil supply shock. The reaction to other types of shocks is not significant.

When we look at the dynamics of the relevant variables in the data, we find that though the fiscal channel may be important for the transmission of natural gas price shocks, we do not see such an effect by looking at the joint dynamics of fiscal data and real oil prices. Analysis of this channel using the SVAR framework applied in the paper is not feasible due to data limitations and is better explored in a more structural DSGE model. This is an interesting topic for future research.

Though the main driving components of headline inflation are food and energy prices, and peaks in international energy prices and food prices coincide with increased inflation in historical data, we also observe periods of high inflation associated with increased global economic activity. We also observe spikes for monetary aggregates. Provided that the countries are relatively open in terms of foreign trade and financial markets, the flow of foreign funds appears to be a significant determinant of domestic demand. Since this flow is positively correlated with global economic activity that also coincides with increased oil prices, it is important to account for the possible endogeneity of oil prices.

We look at the basic structure of the energy sector of the economies in our study. We find that oil price shocks are likely to directly affect the economy through imported oil products and the transportation sector in Georgia, but a higher share of imported natural gas and associated pricing practices of natural gas seem to ameliorate the effects of oil price fluctuations in Armenia. Differences in the structure of energy flows through time and across countries is an important factor in understanding the different effects of oil price shocks across these dimensions.

An interesting further extension of the study would be to analyze the impact of oil shocks in developing economies using a mixed frequency structural model. The results from a FAVAR model would also be interesting though Aastveit (2013) found that the estimated effects using such a model were similar to those from a standard SVAR for the U.S.

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Chapter 3

The Effect of Oil Price Shocks on Oil-Importing Developing Economies: What is the Role of a Weak Interest Rate Channel?

We study the impact of oil price fluctuations on small, open, oil-importing, developing economies focusing on the example of Georgia. Our objective is to understand the role of oil price jumps and relevant transmission channels given the specificities of developing economies. Following Kilian (2009a), we explicitly model fundamental oil shocks in the international oil market in a dynamic stochastic general equilibrium (DSGE) model with New Keynesian features. We concentrate on the monetary policy channel but also look at other transmission channels. A simple extension of the DSGE model allows us to account for the limitations of monetary policy due to dollarization and credibility issues. Key model parameters related to monetary policy and other energy shock transmission channels are estimated using Bayesian methods. Consistent with the evidence from developed countries, we find that macroeconomic variables and monetary policy respond to different types of oil shocks differently. The impact of oil supply shocks is quantitatively small, while oil price changes due to shifts in world economic activity and oil-market-specific demand have strong effects. Thus, we conclude that accounting for the original structural reason for the change in oil prices is important for understanding their impact, even for small open economies. We also find that the role of the monetary policy channel in the transmission of oil price shocks is limited compared to developed economies, but is still quantitatively significant.

Keywords: Oil Shocks, Developing Economies, New Keynesian models

JEL clasification: E32, E52, Q43

1 Introduction

The evolution of oil prices (and energy prices in general) is usually in the front pages of the news and is widely observed and studied by analysts and policymakers. This is not surprising since these prices have properties that warrant intensive interest. First, changes in the prices are often rapid and substantial. Second, energy serves as an input to a wide range of production processes and economic activity in general, thus, its impact is widely spread. Third, the low short-term oil demand elasticity adds to the perception that changes in the price may be particularly harmful. Finally, the oil shock episodes in the 1970's were associated with high rates of inflation and recessions in many developed economies (Bernanke, 2006; Kilian, 2008b).

Our objective is to understand the effects of oil price shocks and the relevant transmission channels in oil-importing developing economies. In particular, we take Georgia as an example of a small open economy that relies on foreign energy imports. We utilize an estimated DSGE model to analyze a number of issues.

First, following a relatively recent trend in the literature, we look at the impact of oil price changes, taking into account the original source of the change. In a series of papers, Kilian argues that in order to understand the impact of oil price shocks on an economy, it is necessary to understand the reason for the increase (Kilian, 2014, 2009a, 2008b). This is relevant for large developed economies such as the U.S., where domestic economic conditions may influence energy prices and vice versa. However, we argue that accounting for the source of oil price change may be even more relevant for the small open economies as they are directly influenced by shifts in global economic activity, which is also a key variable for energy prices. Thus, we differentiate between different types of oil shocks and document their effect in the context of a DSGE model designed to match the characteristics of a *developing* economy.

Second, a priori, the differences in development translate into differences in the transmission channels through which the oil shocks propagate. As argued by Frankel (2011), less developed economies are characterized by less developed institutions and a higher degree of market volatility. The former is manifested in less credible monetary policy, less efficient fiscal system, less competitive banking systems, and imperfect financial markets. The volatility usually stems from the higher exposure to international influences in trade, more pronounced supply and demand shocks in the goods markets, and global financial market influences.

The specificities of developing economies compared to developed industrialized economies directly overlap with the key oil shock transmission channels. For instance, the traditionally endogenous reaction of monetary policy is considered an important determinant of the effects of the swings in oil prices (Bernanke, Gertler,

and Watson, 1997; Blanchard and Galí, 2010; Segal, 2011). This traditional strand of literature argues that the monetary authorities in developed countries can and do trade off some of the inflationary pressures from oil price increases for the aggregate output. Another more recent strand of research argues that the role of monetary policy in the transmission mechanism of oil shocks for developed countries is more limited (Kilian and Lewis, 2011; Leduc and Sill, 2004). Less credible monetary policy and weak interest rate channel in developing economies imply that the role of the monetary policy in accommodating the effects of oil shocks is most likely less pronounced and less efficient. This makes developing countries a natural comparison group.

Thus, we examine the reaction of the central bank to oil price shocks, and the role of weak interest rate channel. We study this question in an estimated DGSE model for Georgia taking the specificities of the monetary policy into consideration. We use our structural model to estimate the effects of responses of key macroeconomic variables to different types of shocks (including different types of oil shocks). We estimate the key parameters for monetary policy rule and the corresponding response of the policy rate to shocks.

We also study the role of a weak interest rate channel in the context of oil price shocks. The weakness is manifested in the reduced capacity of the central bank to affect market interest rates. This may be due to partial dollarization of the economy. Castillo, Montoro, and Tuesta (2013) model partial dollarization in a DSGE framework for a developing economy. They consider different types of partial dollarization: currency substitution – when foreign currency is used for transactions in parallel to the domestic currency; price dollarization – when the prices of domestic goods are indexed to the exchange rate; financial dollarization – when the foreign currency is used as a store of value. Castillo et al. (2013) implement currency substitution in the money-in-the-utility framework with the foreign money stock directly affecting the marginal utility of consumption. Price dollarization is modeled though an additional sector of intermediate producers that index the price of their products to the exchange rate. The authors demonstrate that these forms of dollarization reduce the response of the aggregate variables to the changes in policy interest rate compared to the case of no dollarization. From the modeling standpoint, our objective is to achieve similar effect, but we do not want to impose detailed structure as in Castillo et al. (2013). We emphasize the weak interest rate channel in our model as follows. First, our DSGE model is estimated using data from Georgia and specificities of the interest rate transmission channel affect the parameters of the model. Second, we augment the model with an additional equation that introduces a wedge between the policy rate and the market interest rate that is relevant for the decisions of the agents in the economy.

Before we proceed, we would like to elaborate on the importance of the transmission channels of oil shocks and the sources of oil price shocks. The effects of oil price swings may propagate through various channels. We have already discussed monetary policy as a channel or factor in transmission of the shocks. Another traditional channel explored in the literature is the inflation (supply) channel. Increased energy prices create inflationary pressures as higher prices are reflected in the price of the final energy products. This is often referred to as the first-round effect. The effect may propagate further as firms increase the prices of their products in response to higher input prices (cost channel) and the consumers demand higher nominal wages in response to higher prices in general. This is the second-round effect (Bernanke, 2006). The transmission of the oil price shock through the cost channel may be amplified by microeconomic mechanisms such as time-varying markups and capital utilization (Rotemberg and Woodford, 1996; Finn, 2000; Segal, 2011) and reallocation effects (Davis and Haltiwanger, 2001).

A direct channel runs through the effect of oil price shocks on aggregate demand (analogous to tax on consumption). On the one hand, consumption is affected due to reduced disposable income, increased precautionary savings, and delayed purchases of consumer durables. On the other hand, investment responds as a result of the reduced expected demand faced by the firms (Bernanke, 2006; Kilian, 2008b).

An additional channel relevant to developing countries may be a fiscal channel, since their energy markets are often highly regulated, and some of the impact of energy price fluctuations may be countered through fiscal measures. In contrast, the fiscal channel is rarely discussed in the context of advanced economies in the literature.

The differences in the channels of transmission may be helpful in explaining the differences in the effects of shocks through time and across countries. However, an alternative explanation may be that oil price jumps have different effects if the underlying reason for the price jump is different. As discussed, this is the main idea in a series of studies by Kilian, who argues that flow demand shocks and expectations in the physical market for crude oil are the most significant determinants of oil prices. In comparison, flow supply shocks, financial speculations in oil futures markets, and OPEC activity are less important. The flow demand and market expectations are directly influenced by the state of global economic activity. Thus, he argues that if the increase in oil price is due to, for instance, an overheating global economy, the impact on a specific country will be different compared to a case when the increase is due to a global oil supply shortfall. In the first case, the economy will also be affected by the global economic activity through trade and financial linkages, while in the latter case, most likely no such additional factors are present. Kilian (2009a) uses a simple structural model to identify three main types of shocks that affect

oil prices allowing for shocks to the oil supply, world economic conditions, and the oil-market-specific demand. We utilize identical nomenclature and apply each of the shock types to the model.

The remainder of the chapter is organized as follows. We place the discussion in the context of the relevant literature in the next section. The methodology section that follows includes the description of the DSGE model and the estimation strategy. The final two sections present the results and summarize the implications.

2 Literature Review

Dramatic oil price fluctuations during the 1970's that followed political turmoil in Middle East and coincided with recessions and rampant inflation in many developing countries brought oil price shocks to the forefront of macroeconomic research. Hamilton (1983) noted that most post World War II U.S. recessions were preceded by significant jumps in oil prices. Based on the institutional characteristics of the crude oil market and the exogenous (political) nature of oil supply disruptions for that period and evidence from Granger causality test, Hamilton argued for the causal interpretation running from oil price swings to gross national product growth. A number of studies that followed found similar results for many other developed economies (see Segal (2011) and references therein). Macroeconomics textbooks from the 1980's and later attribute the breakdown of the Phillips curve relationship and the observed stagflation to the oil shocks. However, as new data points became available through the 1990's and 2000's, the impact of oil price shocks appeared to diminish (Blanchard and Galí, 2010). Despite the fact that several incidents of sizable oil price jumps were recorded through the period, no recession and high inflation rates of the magnitude observed in the 1970's followed in the developed economies. Thus, the focus shifted to explaining the differential effect.[1]

The studies in the field closely followed the evolution of the relationship between oil prices and the macroeconomy and tried to explain the large impact in the 1970's and later subdued effects. These studies may be classified based on their focus on either the structure of the economy or the structure of oil shocks. We label the former approach *conventional* as this was the approach taken in the early literature, and we label the latter approach *recent*. An alternative classification may be based on the methodology employed consisting of the studies that employ more empirically oriented variations of SVAR models and the studies that impose more structure in a DSGE framework.

Different strands of conventional literature have analyzed the various mechanisms

[1]Hamilton (2005); Kilian (2014, 2008b); Segal (2011) provide a comprehensive summary of the effects of oil shocks for developed countries although from different perspectives.

that would account for the impact of the oil price changes on developed economies and the diminishing pattern of the impact.

As the standard neoclassical model was not able to quantitatively account for the observed decline in output in the 70's, a number of studies tried to extend the model by adding mechanisms that would amplify the impact of oil price changes. Rotemberg and Woodford (1996) added imperfect competition and time-varying mark-ups, while Finn (2000) augmented the standard model with variable capital utilization. These studies found that their models were able to account for some of the shortfall, compared to the benchmark case without amplification mechanisms. Models with capital-energy complementarities and capital adjustment costs were also tested and shown to imply larger effects of energy price fluctuations on output (Atkeson and Kehoe, 1999).

Another related strand of research focuses on reallocation effects induced by the energy price shifts to account for the asymmetric response of the output (Hamilton, 1988; Davis and Haltiwanger, 2001; Lee and Ni, 2002).

Provided that the monetary authority plays the central role in stabilization policies and responds to various disturbances to the economy either directly or indirectly, it is interesting to investigate its role in the transmission of oil price shocks. A seminal paper by Bernanke, Gertler, and Watson (1997) studies the importance of systematic monetary policy in accounting for the response of output and inflation to the oil shocks of the 1970's using a semistructural VAR model as a primary tool. The authors assume short-term identification restrictions and use Hamilton's net oil price increase as a measure of oil market state indicator.[2] Once the effect is identified, the role of the monetary policy is gauged through counterfactual experiments where the policy rate is fixed to exclude the endogenous reaction of monetary policy. Interestingly, their results indicate that a large portion (almost all in one case) of the decline in output after an oil price shock is due to the endogenous reaction of the monetary policy. They find that systematic monetary policy trades off some of the increase in inflation for the output, i.e., if the policy was not in place, the output would decline less at the expense of higher price levels.

However, Hamilton and Herrera (2004) criticized the study due to the sensitivity of the results to the selection of lag length as well as susceptibility of the counterfactual policy experiments in SVAR framework to the Lucas critique. Though Bernanke et al. (1997) acknowledged the implication of changing economic structure and public expectations for changing policies in the original paper, Hamilton and Herrera (2004) argued that the change in the policy rate required to implement the counterfactual scenario would be too large compared to the observed rates. They

[2]Their monthly SVAR model includes real GDP, GDP deflator, index of spot commodity prices, oil market state indicator, the federal funds rate, and money market interest rates.

also found that the role of endogenous monetary policy was dramatically reduced compared to the benchmark paper under higher VAR lag length suggested by lag selection criteria, though the difference in the response of inflation remained substantial. Nevertheless, Bernanke et al. (2004) argued that their original results still hold (to a weaker extent) in a modified quarterly specification, where the monetary policy response is not fixed forever in counterfactual simulations, but rather delayed for 4 quarters.

More recently Kilian and Lewis (2011) replicated the analysis using more recent data and an updated model. In contrast to the earlier study, they take simple changes in real oil price as a measure of oil price shocks. They find that the effect of the fluctuations in the real price of oil on economic activity, inflation, and short-term interest rates is different for earlier and more recent – post-Volker sample periods. The latter specification does not find strong effects of swings in real oil prices on either the federal funds rate or economic activity. The effect on inflation is also muted in this subsample.

Researchers have utilized various techniques to isolate the exogenous part of oil price changes. Simple oil price changes may still be a useful shortcut to measuring the oil price shocks given the price swings are large and rapid. For instance, Blanchard and Galí (2010) take this approach. A popular measure suggested by Hamilton (1996) is a nonlinear transformation of oil prices that registers only the increase in the nominal oil price from its highest value in the previous four quarters. The rationale for using this measure is that, as argued by Hamilton (1996), it captures the nonlinear relationship between the macroeconomy and oil price changes. Net oil price change is used as a benchmark measure by Bernanke et al. (1997). Other approaches include concentrating on positive oil price increases (Mork's measure) or on price increases associated with the dates of exogenous political events (see the discussion in Bernanke et al. (1997), p. 103).

Oil shocks may also be measured based on oil production rather than on oil price. Dates of political events (such as Iranian revolution and the Gulf War) interacted with the reduction on oil supply may serve as an instrumental variable to oil price changes (Hamilton, 2003). Kilian (2008a) is interested in the effect of oil supply shocks on the key macroeconomic aggregates of G7 countries. He constructs a production based measure of shortfall using actual country-specific series and counterfactual series calculated using oil output growth rates in benchmark country groups not affected by specific supply shock episodes. The identified shocks are used in standard univariate time series regressions to estimate the impulse responses and to conduct historical simulations. Oil supply shocks identified in this manner are shown not to play an important role in crude oil price dynamics.

In general, provided that the oil prices and global economic activity are jointly

determined, it is understood that simple changes in oil prices is not exogenous to the macroeconomic developments in a country that is integrated in the world economy. As noted above, this is especially true for large economies such as the U.S. as the degree of economic activity may influence the global economic activity and eventually the oil prices. However, this may also be relevant for small open economies, as their macroeconomic variables may also react to global influences.

Recently, Kilian has emphasized the endogeneity of oil prices and argued that changes in world oil prices may have different impact on an economy depending on the original source of the change in the price itself (Kilian, 2008b, 2009b; Kilian and Lewis, 2011). Increased global economic activity exerts upward pressure on energy prices. In turn, higher energy prices depress individual country economic activity, which translates into depressed global economic activity. Kilian (2009a) argues that it is not valid to talk about the effect of a rise of the real price of oil *per se* due to the endogeneity of this variable to global economic conditions and ultimately to specific macroeconomic aggregates. He decomposes a sudden rise in real oil prices based on 3 sources: (1) oil supply shocks, (2) global aggregate demand shocks, and (3) oil-market-specific demand shocks. Using a novel monthly measure of global economic activity based on freight rates, Kilian identifies each of the listed shocks in a simple recursive SVAR framework. He estimates that aggregate demand and oil-specific demand shocks account for most of the historical variation in real oil prices. Furthermore, employing a simple univariate time series model, he estimates the impact of each of the shocks on U.S. growth and CPI inflation. He finds that oil supply shocks have limited impact on GDP and inflation, while the two demand shocks result in persistent and significant decline in output and rise in inflation.

Aastveit (2013) studies the impact of the three types of Kilian's oil shocks on the U.S. economy using the FAVAR framework. Unlike the standard SVAR model, a FAVAR model allows more elaborate treatment of information sets faced by policy-makers and is useful for analyzing the role of monetary policy in transmission of oil shocks. He finds that different types of oil shocks have different effects on nominal and real U.S. macroeconomic variables. Oil supply shocks play a relatively minor role only accounting for a small fraction of aggregate fluctuations. Oil-specific demand shock increases real oil price and various price measures and has negative effect on production and unemployment – this is consistent with increased CPI inflation and negative effect on GDP. Global demand shock increases real oil prices and various price measures and has significant negative effect on employment and output with a delay (after two years). Monetary policy is tightened in response to this shock. The effect of oil supply shock is rather small. The real price of oil increases temporarily, but the output, prices, and policy rate are almost unaffected. The FAVAR results are similar to comparable SVAR results with some small differences.

We study the impact of different types of oil shocks on developing economies in a similar SVAR setting focusing on Georgia and Armenia in chapter 2. We find that accounting for the original reason of increase in oil prices matters for understanding their impact. We also find that oil supply shocks lead to small and insignificant effects on all of the variables included in the model, while the oil price shocks due to increased world real activity and oil-market-specific demand shifts have strong and mostly significant effects.

Comprehensive analysis of the energy price swings on emerging economies and associated transmission channels is rather limited. Rasmussen and Roitman (2011) study a large set of developed and developing countries (including oil-importers and oil-exporters) using dynamic panel data methods to control for the endogeneity of oil prices. They look at the response of the cyclical component of GDP, imports, and exports and find a relatively small effect of oil price jumps on oil-importing economies, though the effects increase as the energy intensity of imports increases. The raw correlations of oil price increase with GDP and trade variables is positive and sizable for most economies considered, highlighting the importance of controlling for global economic activity.

Given that the SVAR framework is not ideal for counterfactual experiments, a number of studies examine the role of monetary policy in a DSGE setting. The results are mixed. While some studies do find that a large part of the response of GDP to oil shocks is due to endogenous monetary policy (Leduc and Sill, 2004; Medina and Soto, 2005), the results are not so conclusive in others. Carlstrom and Fuerst (2006) investigate the role of endogenous monetary policy in transmission of oil shocks in a general equilibrium framework employing a standard closed-economy New Keynesian model with sticky wages and prices. Energy input enters production but is not part of consumption. They consider alternative policy rules for the counterfactual response of monetary policy ranging from anticipated and unanticipated Sim and Zha response policies to Wicksellian policy regime. The latter is the rule that keeps the output gap constant and is equivalent to a Taylor rule with a large weight on the output gap. All counterfactual policy responses indicate some role of endogenous monetary policy except for the Wicksellian policy. They interpret this finding against the significance of monetary policy in the transmission of oil price shifts.

Blanchard and Galí (2010) use structural vector autoregressive models to confirm the oil shocks have had lower impact on inflation, output, and wages in a more recent sample for a number of developed countries. Utilizing a simple New Keynesian model with oil sector, they argue that the reduced effect is due to reduced real wage frictions, more credible monetary policy, and lower share of energy.

From a theoretical perspective, Natal (2012) investigates the optimal response

to changes in oil prices in the context of canonical NK monetary model augmented with an oil component in consumption and production. It is well known that the objective function of the central bank that cares about inflation and output gap stabilization may be rationalized based on the second order approximation of representative household's utility (Rotemberg and Woodford, 1998; Benigno and Woodford, 2004). However, in a standard model with sticky prices there is no trade-off between inflation and output gap stabilization. Natal (2012) argues that nominal rigidities in wages do introduce a trade-off, but under standard calibration and appropriate definition of the wage and price inflation index, the trade-off is numerically insignificant. Nevertheless, he demonstrates that a model augmented with an oil sector is able to generate endogenous trade-off between inflation and output gap if the following conditions are met: (1) the modeled economy is distorted and there is no subsidy available to correct for distortion due to the monopolistic power of the firms; (2) oil enters as a gross substitute in the production function and the utility function, i.e., the elasticity of substitution is less than 1, in contrast to the implied value of unitary elasticity of substitution in a standard Cobb-Douglass production function; (3) the presence of oil in the consumption bundle increases the trade-off as increases in oil prices act as a consumption tax. When these conditions hold as the oil shock is realized, natural distorted output under flexible prices decrease by more than the efficient output, thus creating an endogenous trade-off with the gap between the efficient and distorted output acting as a cost-push shock (higher monopolistic mark-up and lower elasticity of substitution imply a larger gap). The DGSE model estimated in our paper satisfies all three requirements.

Bodenstein et al. (2012) analyze the response of U.S. monetary policy to oil price shocks in an estimated DSGE model, explicitly modeling the underlying structural shock behind oil price fluctuations. They demonstrate that given the estimated monetary policy reaction function, the response of monetary policy to different types of underlying structural oil shocks is different. The authors also compare the estimated monetary policy rule to one optimized based on welfare analysis, and conclude that the estimated policy rule differs from the optimal rule.

3 Methodology

We estimate a small open economy DSGE model using Bayesian methods. The model is designed to match the characteristics of the developing economy in this study (Georgia). The external sector is specified to allow different types of oil shocks consistent with the evidence discussed above.

The advantages of Bayesian estimation are well known and allow us to address the misspecification and identification issues (Lubik and Schorfheide, 2006; An and

Schorfheide, 2007).

3.1 DSGE Model

The DSGE model used is a small open economy version of the canonical New Keynesian model (Woodford, 2003) augmented with an oil sector. Natal (2012) studies optimal monetary policy design under a comparable but closed economy setting. Our model closely follows that used by Medina and Soto (2005) with some additional features such as different external sector with a world oil market, weak interest rate channel, and incomplete pass-through to import prices. The choice of model is motivated by the fact that it is widely accepted and used in the field due to its simplicity that would make the intuitive comparisons across countries feasible. The summary of all the model equations and description of the variables is presented in Appendix 3A.

The model features nominal rigidities in price-setting and wage-setting as well as price and wage indexation. Oil products are consumed by households and used by intermediate firms as an input. As discussed earlier, such a setting implies from a theoretical point of view a greater trade-off between inflation and output gap stabilization and may explain the behavior of the central banks that accommodate some of the supply shocks rather than fully stabilizing prices.

The domestic economy is populated by a large number of representative households, intermediate and final goods producers, importers, a labor aggregator, government, and central bank. The foreign sector is modeled as a set of interrelated exogenous processes that cannot be affected by domestic variables.

Households

The households choose a lifetime of expected discounted consumption (C) and leisure ($1-l$) streams, and real money balances (M_n/P) based on the following objective function.

$$U_t = E_0 \sum_{t=0}^{\infty} \left\{ log(C_t(j) - hC_{t-1} + \frac{a}{\mu} \left(\frac{M_{n,t}(j)}{P_t} \right)^{\mu} - \frac{\zeta_t}{1+\sigma_L} l_t(j)^{1+\sigma_L} \right\} \tag{3.1}$$

The aggregate consumption variable is characterized by external habit formation, often used to account for the empirical high persistence of consumption and output. Parameter $h \in [0,1]$ determines the degree of habit persistence. Higher values of h indicate a larger role of past consumption. Labor supply is subject to stochastic preference shock – ζ given as an exogenous process. σ_L is the inverse labor supply elasticity. μ determines the interest rate elasticity of money demand.

The composite consumption good (C) consists of consumable oil products (O_c), domestically produced goods (C_H), and imported goods (C_F). Oil imported from abroad enters consumption and is also used in domestic production. Different components of consumption are nested through a CES aggregator:

$$C_t = \left((1-\delta)^{\frac{1}{\eta}} Z_t^{\frac{\eta-1}{\eta}} + \delta^{\frac{1}{\eta}} O_C^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}} \tag{3.2}$$

$$Z_t = \left((1-\gamma)^{\frac{1}{\theta}} C_{H,t}^{\frac{\theta-1}{\theta}} + \gamma^{\frac{1}{\theta}} C_{F,t}^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \tag{3.3}$$

Here Z is a combined domestically produced and imported non-energy consumption – core consumption.[3] δ is the share of oil and its derivative products in consumption, and η is the relevant elasticity of substitution between energy and non-energy consumption. Similarly, γ is the share of imported non-energy products purchased from domestic importers, and θ is the elasticity of substitution between home-produced and imported non-energy products.

Given prices and the overall consumption level, consumers choose the optimal levels of the consumption components by solving the static cost-minimization problem.

$$O_{Ct} = \delta \left(\frac{P_{Ot}}{P_t}\right)^{-\eta} C_t \tag{3.4}$$

$$Z_t = (1-\delta) \left(\frac{P_{Zt}}{P_t}\right)^{-\eta} C_t \tag{3.5}$$

$$P_t = (\delta P_{Ot}^{1-\eta} + (1-\delta) P_{Zt}^{1-\eta})^{\frac{1}{1-\eta}} \tag{3.6}$$

$$C_{Ft} = \gamma \left(\frac{P_{Ft}}{P_{Zt}}\right)^{-\theta} Z_t \tag{3.7}$$

$$C_{Ht} = (1-\gamma) \left(\frac{P_{Ht}}{P_{Zt}}\right)^{-\theta} Z_t \tag{3.8}$$

$$P_{Zt} = (\gamma P_{Ft}^{1-\theta} + (1-\gamma) P_{Ht}^{1-\theta})^{\frac{1}{1-\theta}} \tag{3.9}$$

The headline price level (P) and core price level (P_Z) are equivalent to the marginal cost from the consumer cost-minimization problem. The domestic price of oil (P_O) is set by the domestic oil import firms and may be considered as an index for the price of imported refined oil products. While there may be a different mix of refined oil products used by consumers and firms, we use effectively the same price for firms that use oil products in their production process.

On the income side, the households receive wage (W) for their labor services (l)

[3]Since all households are identical ex-post, I omit the household-specific subscript. The homogeneity arises from complete domestic asset markets.

provided to firms; dividends from the firms' profits and remittances (Ω); and government and foreign transfers (T). The consumers are able to trade state-contingent nominal claims ($B(j)$) domestically, which makes the consumers homogeneous inside the economy. They also have access to non-contingent foreign debt markets with the country premium ($\Theta(.)$), which depends on the level of domestic claims ($B^\star$) relative to the capacity of the economy. It is also possible to maintain a stock of national currency (cash) that yields no returns but directly generates utility. The intertemporal budget constraint that holds for every possible state and period may be written as follows.

$$E_t\{Q_{t,t+1}B_{t,t+1}(j)\} + \frac{S_t B_t^\star(j)}{(1+i_t^\star)\Theta(\frac{S_t B_t^\star}{P_{Xt}X_t})} + M_{n,t(j)} =$$
$$B_{t-1}(j) + S_t B_{t-1}^\star(j) + M_{n,t-1}(j) + W_t(j)l_t(j) + \Omega_t(j) + T_t(j) - P_t C_t(j). \quad (3.10)$$

Given the interest rate in the world markets ($i^\star$), the agents may borrow at premium from the world based on the size of foreign debt ($-B^\star$) relative to the size of their home economy. Following Medina and Soto (2005), I measure the foreign debt relative to the value of exports ($P_X X$). S_t is the nominal exchange rate defined as the value of one unit of foreign currency in terms of domestic currency. The parameters of the premium expression below are chosen to match the average premium ($\bar{\Theta}$) and the debt elasticity (ϱ) of the premium for the country.

$$\Theta(b_t^\star) = \bar{\Theta}\exp\left\{-\varrho(b_t^\star - \bar{b}^\star)\right\}, \quad (3.11)$$
$$b_t^\star \equiv \frac{S_t B_t^\star}{P_{Xt}X_t}. \quad (3.12)$$

The term Ω in equation (3.10) includes the profits of producers and importers, and remittances from abroad. The latter part is modeled as an exogenous process that may depend on the state of home and foreign economies.

Given the budget constraint (3.10), prices, profits, remittances, and transfers, households maximize the objective function (3.1) by choosing the values of consumption, money balances, domestic and foreign bond-holdings for each period and state. Households also decide on labor supply to the labor-aggregator firm. Since households exercise some monopoly power, they can choose the wage given the demand of the labor-aggregator firm. However, wage-setting decisions are subject to a Calvo-Yun type constraint, i.e., in every period, each household faces a probability $(1-\phi_L)$ that it will be able to set the wage optimally. Otherwise, the wages are adjusted for observed inflation in the previous period (Π) and the steady-state

inflation rate ($\bar{\Pi}$) according to the following adjustment rule.

$$\Xi_{Wt}^{k} = \prod_{i=1}^{k} \Pi_{t+i-1}^{\xi_L} \bar{\Pi}^{1-\xi_L}, \tag{3.13}$$

where parameter ξ_L determines the share of previous period inflation relative to the steady-state inflation in indexation rule. The relevance of wage indexation for Georgia is an empirical question to be tested.

The labor aggregator firm transforms individual labor hours into aggregate labor hours through the CES aggregator function. As discussed earlier, individual labor hours are imperfect substitutes in generating aggregate labor hours with an elasticity of substitution of ϵ_L.

$$l_t = \left(\int_0^1 l_t(j)^{\frac{\epsilon_L - 1}{\epsilon_L}} dj \right)^{\frac{\epsilon_L}{\epsilon_L - 1}} \tag{3.14}$$

Minimization of expenditures on labor inputs subject to fixed aggregate labor hours yields labor demand schedule faced by individual consumers and the wage index:

$$l_t = \left(\frac{W_t(j)}{W_t} \right)^{-\epsilon_L} l_t, \tag{3.15}$$

$$W_t = \left(\int_0^1 W_t(j)^{1-\epsilon_L} dj \right)^{\frac{1}{1-\epsilon_L}}. \tag{3.16}$$

If we return to the consumers' optimization problem, the optimal wage is chosen based on the objective function below.

$$U_{Wt} = E_t \left\{ \sum_{k=1}^{\infty} \phi_L^k Q_{t,t+k} \left(\frac{W_t(j) \Xi_{Wt}^k}{P_{t+k}} - \zeta_{t+k} l_{t+k}^{\sigma_L} (C_{t+k}(j) - h C_{t+k-1}) \right) l_{t+k}(j) \right\}. \tag{3.17}$$

The expected benefit terms in the sum above are discounted by the probability that it will not be possible to adjust the wage optimally and the discount factor $Q_{t,t+k}$.

Wage dynamics derived from the optimization problem results in a Phillips curve type relationship that may be summarized in the following manner (two auxiliary variables – χ_1^W and χ_2^W – are introduced to write the infinite sum from the first-order

condition in recursive form).

$$\left(\frac{(W_t/P_t\Pi_t)^{1-\epsilon_L} - \phi_L(W_{t-1}/P_{t-1}\Pi_{t-1}^{\xi_L}\bar{\Pi}^{1-\xi_L})^{1-\epsilon_L}}{1-\phi_L}\right)^{\frac{1+\epsilon_L\sigma_L}{1-\epsilon_L}} \chi_{1t}^W = \frac{\epsilon_L(1+\sigma_L)}{\epsilon_L - 1}\chi_{2t}^W, \tag{3.18}$$

$$\chi_{1t}^W = \frac{(W_t/P_t)^{\epsilon_L}\Pi^{\epsilon_L - 1}l_t}{C_t - hC_{t-1}} + \phi_L\beta\Pi_t^{\epsilon_L - 1}(\Pi_t^{\xi_L}\bar{\Pi}^{1-\xi_L})^{1-\epsilon_L}E_t\chi_{1,t+1}^W, \tag{3.19}$$

$$\chi_{2t}^W = (W_t/P_t)^{\epsilon_L+\epsilon_L\sigma_L}\Pi_t^{\epsilon_L+\epsilon_L\sigma_L}\zeta_t l_t^{1+\sigma_L} + \phi_L\beta\Pi_t^{\epsilon_L+\epsilon_L\sigma_L}(\Pi_t^{\xi_L}\bar{\Pi}^{1-\xi_L})^{-(\epsilon_L+\epsilon_L\sigma_L)}E_t\chi_{2,t+1}^W. \tag{3.20}$$

Remaining optimality conditions from the households' problem characterize the optimal choice of domestic and foreign bonds respectively:

$$1 = \beta E_t\left\{\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t}\frac{1+i_t}{\Pi_{t+1}}\right\}, \tag{3.21}$$

$$1 = \beta E_t\left\{\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t}\frac{\Delta S_t}{\Pi_{t+1}}(1+i_t^\star)\Theta(b_t^\star)\right\}. \tag{3.22}$$

The former is the Euler equation, and the latter would result in the familiar UIP condition if linearized. However, we write the model in a non-linear form, making it amendable to higher order approximation techniques.

Producers

Domestic goods are effectively produced by two layers of firms: The first layer consists of perfectly competitive final producers that aggregate intermediate goods and supply domestically and abroad. The second layer consists of a large number of domestic oligopolistic producers that use labor (L) and imported oil (O_H) to manufacture intermediate goods.[4]

The final goods are produced through the CES production function. Similar to the labor aggregator's problem, we can derive factor demands and final prices based on a cost minimization problem and the standard assumption on perfect competition setting the price equal to the marginal cost.

[4]Alternatively, we my think of the final producers as the ultimate consumers that minimize their costs in choosing a basket of intermediate goods.

$$Y_{Ht}(j) = \left(\frac{P_{Ht}(j)}{P_{Ht}}\right)^{-\epsilon_H} Y_{Ht}, \tag{3.23}$$

$$P_{Ht} = \left(\int_0^1 P_{Ht}(j)^{1-\epsilon_H} dj\right)^{\frac{1}{1-\epsilon_H}}. \tag{3.24}$$

The following equation is a production function of a typical intermediate producer. Y_H is the output of the intermediate good, α is the share of oil in production and ω is the elasticity of substitution between the two production factors. A_H is a stationary technology shock common to all intermediate firms.

$$Y_{Ht}(i) = A_{Ht}\left((1-\alpha)^{\frac{1}{\omega}} L_t(i)^{\frac{\omega-1}{\omega}} + \alpha^{\frac{1}{\omega}} O_{H,t}(i)^{\frac{\omega-1}{\omega}}\right)^{\frac{\omega}{\omega-1}} \tag{3.25}$$

The growing trend of the economy is modeled through labor-augmenting technology process, which may simply be a deterministic trend (Medina and Soto, 2005) or a non-stationary process with a drift (Lubik and Schorfheide, 2006).

We can derive factor demands and marginal cost by minimizing the cost subject to fixed output in equation (3.25). Note that the marginal cost is not firm-specific due to the constant-returns-to-scale technology.

$$L_t(i) = (1-\alpha) MC_t \frac{W_t^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha P_{Ot}^{1-\omega}} Y_{Ht}(i) \tag{3.26}$$

$$O_{Ht}(i) = \alpha MC_t \frac{P_{Ot}^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha P_{Ot}^{1-\omega}} Y_{Ht}(i) \tag{3.27}$$

$$MC_t = A_{Ht}^{-1}[(1-\alpha) W_t^{1-\omega} + \alpha P_{Ot}^{1-\omega}]^{\frac{1}{1-\omega}} \tag{3.28}$$

The producers set the prices in the Calvo-Yun manner, implying that every period a typical producer faces a fixed probability (ϕ_h) that it will not be able to set the price on their product optimally, but but may only adjust it for past and long-term inflation. In this case the indexation is slightly different:

$$\Xi_{Ht}^k = \prod_{i=1}^{k} \Pi_{H,t+i-1}^{\xi_H} \bar{\Pi}^{1-\xi_H}, \tag{3.29}$$

However, when the price is set optimally, producers take into account that they may be constrained in setting prices in the future. This leads to the inflation dynamics described by the New Keynesian Phillips curve. A typical intermediate producer

sets its price (if possible) according to the rule that maximizes the objective function below.

$$U_{Ht} = E_t \left\{ \sum_{k=1}^{\infty} \phi_H^k Q_{t,t+k} \left(\frac{P_{Ht}(j)\Xi_{Ht}^k}{P_{t+k}} - \frac{MC_{t+k}}{P_{t+k}} \right) Y_{H,t+k}(j) \right\}. \tag{3.30}$$

We can write the resulting FOC into recursive form using auxiliary variables.

$$\left(\frac{\Pi_{Ht}^{1-\epsilon_H} - \phi_H (\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_h})^{1-\epsilon_H}}{1-\phi_H} \right)^{\frac{1}{1-\epsilon_H}} \frac{P_{H,t-1}}{P_{t-1}} \chi_{1t}^H = \frac{\epsilon_H}{\epsilon_H - 1} \chi_{2t}^H \tag{3.31}$$

$$\chi_{1t}^H = \frac{Y_{Ht}}{C_t - hC_{t-1}} \Pi_{Ht}^{\epsilon_H} \Pi_t^{-1} = \phi_H \beta (\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{1-\epsilon_H} \Pi_{Ht}^{\epsilon_H} \Pi_t^{-1} E_t \chi_{1,t+1}^H \tag{3.32}$$

$$\chi_{2t}^H = \frac{Y_{Ht}}{C_t - hC_{t-1}} \Pi_{Ht}^{\epsilon_H} \frac{MC_t}{P_t} = \phi_H \beta (\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{-\epsilon_H} \Pi_{Ht}^{\epsilon_H} E_t \chi_{2,t+1}^H \tag{3.33}$$

The three equations above represent the New Keynesian Phillips curve for the domestic production sector written in nonlinear form.

Some of the equations (specifically the factor demands) are still specific to individual intermediate producers. We need to write them in terms of aggregate variables rather then specific variables related to particular firms on the unit interval. We can easily aggregate the factor demands by the individual intermediate firms.

$$L_t = \int_0^1 L_t(i)di = (1-\alpha) MC_t \frac{W_t^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha P_{Ot}^{1-\omega}} P_{Ht}^d Y_{Ht}, \tag{3.34}$$

$$O_{Ht} = \int_0^1 O_{Ht}(i)di = \alpha MC_t \frac{P_{Ot}^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha P_{Ot}^{1-\omega}} P_{Ht}^d Y_{Ht}, \tag{3.35}$$

where $P_{Ht}^d \equiv \int_0^1 (P_{Ht}(j)/P_{Ht})^{-\epsilon_H} di$ is a price dispersion with a specified law of motion (not shown here for brevity).[5]

Importers

Imported goods are not directly available to consumers but can be obtained through domestic importers that purchase the foreign goods at world prices, repackage them, and offer the final product at a markup. This element is used to achieve imperfect pass-through of world commodity price changes to a domestic economy. Similar to domestic producers, the importers are also subject to frictions in setting the prices

[5]Derivations of price dispersion may be found in Schmitt-Grohé and Uribe (2007), p.18

on imported merchandise. In this case, the difference is that price of a foreign good converted to domestic currency would be the marginal cost of the importers:

$$U_{Mt} = E_t \left\{ \sum_{k=1}^{\infty} \phi_M^k Q_{t,t+k} \left(\frac{P_{Ft}(j)\Xi_{Ft}^k}{P_{t+k}} - \frac{S_t P_{FT}^\star}{P_{t+k}} \right) C_{H,t+k}(j) \right\}. \tag{3.36}$$

Similar to previous results we can summarize the Phillips curve type relationship in imports sector in a recursive form (which I once again omit for brevity).

Oil products are also imported from the world market. A look at the raw data on international and domestic energy prices shows that there is a pass-through from the former to the latter (c.f. p.20 in chapter 2). However, there is also some evidence that fuel importers exercise some monopoly power (TIG, 2012). Thus, we allow for short-run deviation from the law of one price, but assume that it holds in the long run. Medina and Soto (2005) follow a similar strategy for the Chilean economy and motivate the choice based on the existence of an oil stabilization fund in the country.

$$P_{Ot} = S_t P_{Ot}^\star \exp\{\psi_t\}, \tag{3.37}$$

$$\psi_t = \rho_\psi \psi_{t-1} + e_t^\psi. \tag{3.38}$$

Market clearing

The goods produced in the domestic economy (Y_H) are ultimately consumed domestically (C_H) or exported abroad ($C_H^\star$).

$$Y_{Ht} = C_{Ht} + C_{Ht}^\star. \tag{3.39}$$

Domestic imports (M_H) consist of non-energy consumption goods produced abroad (C_F) and imported oil products, which are used either in consumption (O_C) or as an input for production (O_H).

$$PR_{Mt} M_t = PR_{Ft} C_{Ft} + PR_{Ot}(O_{Ct} + O_{Ht}) \tag{3.40}$$

$$PR_{Mt} = PR_{Ft}^{\bar{C_F}/\bar{M}} PR_{Ot}^{1-\bar{C_F}/\bar{M}} \tag{3.41}$$

Here PR_{Mt}, PR_{Ft}, and PR_{Ot} are the corresponding relative prices. The relative price of imports (relative to domestic CPI) is a weighted index of non-energy and energy components weighted by their steady-state shares.

The budget constraint from the consumers problem reduces to the following equation that determines the evolution of foreign debt:

$$\frac{b_t^\star}{(1+i_t^\star)\Theta(b_t^\star)} - \frac{b_{t-1}^\star \Delta S_t}{\Pi_t(1+g_y)} \frac{PR_{X,t-1}X_{t-1}}{PR_{Xt}X_t} = 1 - \frac{PR_{Mt}M_t - Q_t TF_t}{PR_{Xt}X_t}, \tag{3.42}$$

where X stands for exports with corresponding relative price of PR_X. Q is the real exchange rate defined as the ratio of domestic and foreign price levels $Q_t = S_t P_t^\star / P_t$. Transfers from the world economy (TF) are determined as an exogenous AR process.

Monetary Policy

Monetary policy response is modeled as a standard Taylor type rule:

$$1 + i_{pt} = (1 + i_{p,t-1})^{\rho_i} \left[(1 + \bar{i_p}) \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{\omega_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\omega_Y} \left(\frac{\Delta S_t}{\Delta \bar{S}_t} \right)^{\omega_S} \right]^{1-\rho_i} \exp\{e_t^i\}; \tag{3.43}$$

i_p is a policy rate set by the central bank according to the above rule reacting to the deviation of inflation from the target, an empirical measure of output gap, and currency depreciation. The policymakers also place some value on nominal interest rate stabilization captured in parameter ρ_i. We do not a priori claim that the central bank directly reacts to exchange rate movements, but, nevertheless, estimate the reaction parameter ω_S together with the other parameters in the Taylor rule. Though Georgia has been moving to an inflation targeting regime only since about 2008, we decided to model monetary policy via this rule rather than a monetary targeting rule.

Given the high degree of dollarization (of about 60% for deposits and loans) and possible credibility issues, the monetary policy rate only partially affects the interest rates relevant to the agents in the economy. In particular, we assume that the interest rate faced by agents is a weighted average of the policy rate and the premium adjusted UIP rate.

$$1 + i_t = (1 + i_{pt})^\kappa [(1 + i_{t-1}^\star) \Delta S_t \Theta(b_{t-1}^\star)]^{1-\kappa} \exp\{e_t^d\}; \tag{3.44}$$

Parameter κ determines the strength of the impact of the policy rate. If κ is set to one, the interest rate channel in the model is strong and controlled by the central bank. This parameter is estimated with diffuse prior.

External Sector

The variables for the foreign (world) economy are modeled as exogenous processes with no feedback from economic variables in the home country. However, we would like to capture dynamics of the world oil market. One option is to set up a parallel

world economy analogous to a domestic economy with an exogenous oil supply.[6] In order to avoid a large model and over-parametrization, we opted for a simpler structure similar to that utilized in SVAR literature. World oil supply growth, world economic activity and real oil price are modeled as exogenous process subject to short-term restrictions commonly found in the literature. In particular, as illustrated below, oil supply growth is not affected by the other two variables in the current period. World economic activity is contemporaneously affected by oil supply growth shocks only, while the real price of oil reacts to shocks to the other variables in the same period when the shocks occur.

$$\Delta Oil_t^\star = (\Delta Oil_{t-1}^\star)^{\rho_{do}^\star} exp(\epsilon_{do^\star t}) \tag{3.45}$$

$$C_t^\star = (C_{t-1}^\star)^{\rho_{c^\star}} (\Delta Oil_t^\star)^{\mu_{c^\star do}} exp(\epsilon_{c^\star t}) \tag{3.46}$$

$$PR_{ot}^\star = (PR_{o,t-1}^\star)^{\rho_{o^\star}} (C_t^\star/\bar{C}^\star)^{\mu_{oc^\star}} (\Delta Oil_t^\star)^{\mu_{odo}} exp(\epsilon_{o^\star t}); \tag{3.47}$$

Here $\Delta Oil_t^\star$ is physical oil supply growth; $C_t^\star$ is a measure of world economic activity, and $PR_{ot}^\star$ is the real price of oil. Parameters $\mu_{c^\star do}, \mu_{oc^\star}$ and μ_{odo} that govern the contemporaneous relationships between the variables are estimated together with the other parameters of the model.

The shocks to the oil supply growth ($\epsilon_{do}^\star$), world economic activity ($\epsilon_{c^\star}$), and real price of oil ($\epsilon_{o^\star}$) in our model may be interpreted respectively as oil supply, global economic activity, and oil-market-specific demand shocks.

3.2 Parameters

The model contains a significant number of structural parameters that may be divided into two groups. The calibrated parameters are listed in Table 3.1. Table 3.2 displays the description and priors for the estimated parameters.

The former category contains the parameters that determine steady-state values of the model variables and are set based on corresponding moments in the data rather than by the Bayesian estimation procedure. Examples include the share of oil input in production (α) and the share of fuel in consumption (δ) calibrated based on imported oil to GDP ratio and the weight of the energy related basket in domestic CPI. Similarly the share of imports (γ) and exports ($\gamma^\star$) in domestic and foreign consumption are set based on the corresponding long-term ratios of imports and exports to GDP.[7]

[6] Bodenstein et al. (2012) and Kilian (2014) discuss why it is reasonable to model oil supply as an exogenous process.

[7] A more detailed analysis of the economic and energy structure of the Georgian (and Armenian) economy may be found in chapter 2.

Table 3.1: Calibrated Parameters

Name	Description	Value
α	Share of oil input in production	0.0145;
β	Subjective discount factor	$0.99^{0.25}$
δ	Share of fuel in consumption	0.04
ϵ_h	Elasticity of substitution b/t home produced intermediate goods	9
ϵ_l	Elasticity of substitution b/t labor types	9
ϵ_m	Elasticity of substitution b/t imported intermediate goods	9
γ	Share of foreign goods in core consumption	0.4
$\gamma^\star$	Share of domestic goods in foreign consumption	0.0015
g_y	Output growth rate in a model with deterministic trend	$1.05^{0.25} - 1$
Θ	Risk premium for nominal interest rate	1.009

We do not estimate elasticities of substitution between intermediate inputs (ϵ_h and ϵ_m) and labor types (ϵ_l), and set them to the common value found in the literature. These variables determine the level of price and wage markups compared to the case of perfect competition. As discussed in Iskrev (2010), these parameters are difficult to identify when the degrees of nominal rigidities are also estimated.

The long-term risk premium is determined according to the following formula and reflects differentials in inflation targets at home and abroad.

$$\bar{\Theta} = \frac{(1+\bar{i})\bar{\Pi}^\star}{(1+\bar{i}^\star)\bar{\Pi}} \tag{3.48}$$

g_y is steady-state growth rate of the output for the version of the model with alternative deterministic trends. We decided to remove the trends from the data using a one-sided Hodrick-Prescott filter. Thus, we set the value of g_y to zero.

We set relatively loose priors for the parameters estimated using the Bayesian method. For instance, the priors for the habit persistence (h) and the interest rate channel strength parameters (κ) are selected so that the 90% interval includes values close to zero and one. Similarly the degrees of price and wage rigidities and indexation were selected to allow for a wide range of outcomes. The prior mean values were selected based on estimates from previous studies (Lubik and Schorfheide, 2006; Medina and Soto, 2005).

Though all of the parameter estimates are interesting, we would like to concentrate on those that determine the contemporaneous interactions in the international oil market – $\mu_{c^\star do}, \mu_{oc^\star}$ and μ_{odo}. We estimated a SVAR model similar to that in Kilian (2009a) and Aastveit (2013), and chose the priors based on the recursively identified matrix of coefficients in that model.

Another variable of particular interest is κ that determines the ability of the central bank to affect the interest rate channel. The variable is in (0,1) interval;

Table 3.2: Priors for Estimated Parameters

Name	Description	Density	Mean	SD	90% interval
η	Elasticity of substitution b/t fuel and core consumption	Inv. Gamma	0.2	0.05	0.13 0.29
h	Habit persistence in consumption	Beta	0.5	0.25	0.10 0.90
κ	Interest rate channel strength	Beta	0.5	0.25	0.10 0.90
$\mu_{c^\star,do}$	Effect of oil production growth on oil global economic activity (GEA)	Normal	0.10	0.10	-0.07 0.26
$\mu_{o,do}$	Effect of oil production growth on real price of oil	Normal	-0.07	0.10	-0.23 0.10
$\mu_{oc^\star}$	Effect of GEA on oil price	Normal	0.10	0.15	-0.04 0.29
ω_e	Policy response to exchange rate	Normal	0	0.01	-0.08 0.08
ω_π	Policy response to inflation	Normal	2	0.40	1.34 2.64
ω_y	Policy response to output gap	Normal	0.15	0.01	0.13 0.17
ϕ_h	Price rigidity for domestic goods	Beta	0.75	0.15	0.47 0.95
ϕ_l	Wage rigidity	Beta	0.75	0.15	0.47 0.95
ϕ_m	Price rigidity for imported goods	Beta	0.75	0.15	0.47 0.95
σ_l	inverse elasticity of labor supply	Inv. Gamma	1	0.20	0.72 1.36
θ	Elasticity of substitution b/t home and foreign produced goods	Inv. Gamma	0.5	0.10	0.36 0.68
ϱ	Elasticity of the upward slopping supply of international funds	Inv. Gamma	0.005	0.05	0.001 0.14
ω	Elasticity of substitution b/t oil and labor inputs in production.	Inv. Gamma	0.2	0.05	0.13 0.29
ξ_h	Price indexation for domestic goods	Beta	0.5	0.15	0.25 0.75
ξ_l	Wage indexation	Beta	0.5	0.15	0.25 0.75
ξ_m	Price indexation for imported goods	Beta	0.5	0.15	0.25 0.75
ρ_a	AR param. for TFP process	Beta	0.5	0.20	0.17 0.83
$\rho_{c^\star}$	AR param. for foreign consumption	Beta	0.5	0.20	0.17 0.83
$\rho_{do^\star}$	AR param. for oil supply growth	Beta	0.5	0.20	0.17 0.83
ρ_i	Nominal interest rate smoothing	Beta	0.75	0.20	0.35 0.99
$\rho_{i^\star}$	AR param. for foreign interest rate	Beta	0.5	0.20	0.17 0.83
$\rho_{o^\star}$	AR param. for real oil price	Beta	0.5	0.20	0.17 0.83
$\rho_{\pi^\star}$	AR param. for foreign inflation	Beta	0.5	0.20	0.17 0.83
ρ_ψ	AR param. oil price LOP gap	Beta	0.5	0.20	0.17 0.83
ρ_{tf}	AR param. for remittances	Beta	0.5	0.20	0.17 0.83
ρ_ζ	AR param. for labor supply shock	Beta	0.5	0.20	0.17 0.83

since it was difficult to select a specific value, we set it to 0.5 with rather high standard deviation.

3.3 Data

Twelve observable data series used for estimation are shown in Figure 3.1.[8] The series span 54 quarters staring in 2001Q1 and ending in 2014Q2. Variables that

[8]We have 10 structural shocks in the model including the three types of oil shocks and the monetary policy shock as well as 2 measurement errors.

tested positively for seasonality were adjusted using X13-ARIMA-SEATS seasonal adjustment procedure. Trending variables were detrended using a one-sided Hodrick-Prescott filter.

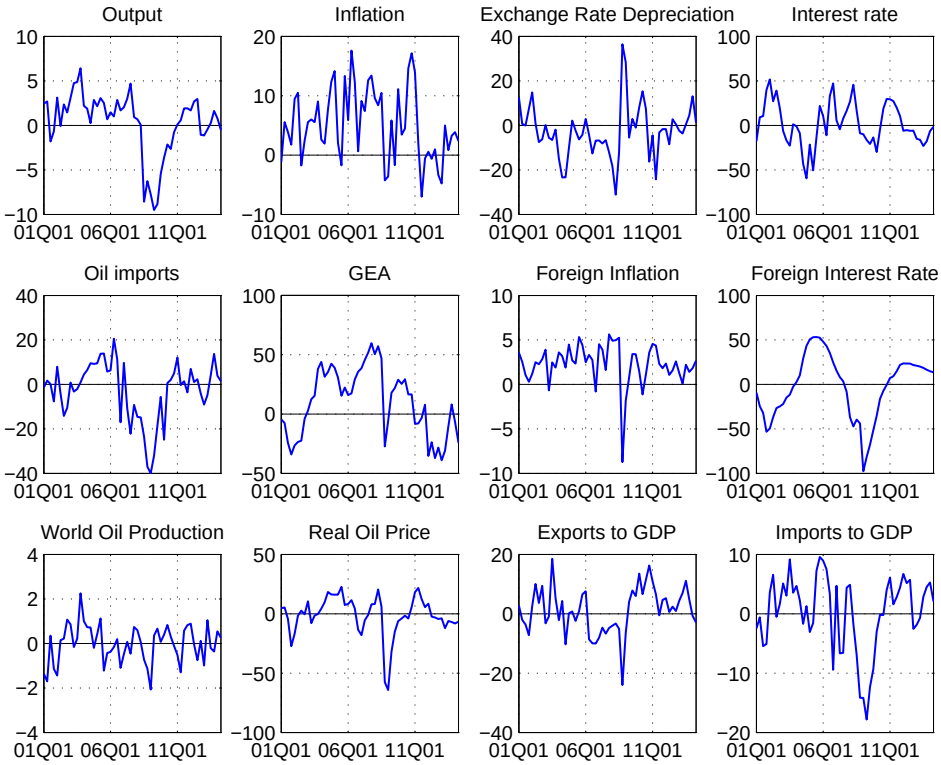

Figure 3.1: Observable Variables Used in Estimation.

The list includes key variables of interest for Georgia such as the real GDP, headline inflation, exchange rate depreciation, and the interbank interest rate. We have parallel variables for the foreign (world) economy such as a measure of world economic activity (available from Kilian (2009a)), U.S. inflation, and the short-term (one-month) LIBOR rate. The world oil market variables include growth of the physical oil supply and the real price of oil. The latter two variables combined with the measure of global economic activity comprise the necessary variables to specify the model for the world oil market and identify different types of oil shocks. CPI deflated domestic oil imports are also used for estimation.

There are a few data issues stemming from limited data availability. First, real GDP components based on final use are not available for Georgia. This is one of the reasons for not explicitly including capital into the model. Second, the import and export prices indexes are also not available. However, given that, theoretically, trade channel may be an important factor in the transmission of oil shocks, we include nominal exports and nominal imports divided by the nominal GDP in the observables. Finally, though quarterly frequency employments and wages data would be be very helpful in properly identifying the dynamics in labor supply and wages,

unfortunately, such data are not available.[9]

4 Results and Discussion

First, we look at the posterior estimates of the key parameters related to the monetary policy and the oil shock transmission channels. The impulse responses to the monetary policy shock, and different types of oil shocks are analyzed afterwards.

4.1 Estimated Parameters

Table 3.3 displays the values of the estimated parameters. Posterior means, posterior modes, and 90% confidence intervals are shown in the last three columns. There are a few interesting observations related to the monetary sector of the Georgian economy in general as well as the oil sector specific variables.

First, the estimated values of most of the parameters are consistent with those found in previous studies. The posterior mean values for the price and wage rigidities indicate an average contract length of 5.2, 4.0, and 3.0 quarters for domestic intermediate goods prices, nominal wages, and imported intermediate goods prices respectively. Similarly, there is some evidence of price and wage indexation. The degree of indexation is much higher for imported intermediate goods compared to domestic intermediate goods (49% vs. 22%). Wages are indexed to past inflation at about 32%. The level of habit persistence in consumption of 0.65 is also in line with earlier findings. For instance, Barseghyan (2013) finds that the corresponding value of the habit persistence parameter is 0.49 for Armenia in a New Keynesian DSGE model.

Second, the estimates of the Taylor rule indicate that the central bank responds to deviation of inflation from the long-term target and to a lesser degree to the empirical measure of output gap. Moreover, there is evidence that the monetary authority tightens its stance following currency depreciation. Interestingly, the estimate of the interest rate smoothing parameter (ρ_i) is rather low compared to the value found in the literature for developed and developing countries. For example,

[9]Most of the series used for estimation are available free of charge from public sources (and from the author upon request). The interbank interest rate series for Georgia is an exception and was obtained from the International Monetary Fund's IFS database. A similar series is available from official Georgian public sources, but is significantly shorter. Real GDP for Georgia is from GeoStat – a national statistical agency. Data for headline CPI, exchange rate, nominal imports and exports, and oil imports for Georgia come from the National Bank of Georgia. As mentioned, the data for the world economic activity measure are from the associated website of Kilian (2009a). The world oil production data are available from the U.S. Energy Information Administration. We use U.S. CPI deflated Brent spot oil prices as our measure of international oil prices relevant for Georgia. The series was obtained from the World Bank. U.S. inflation comes from the U.S. BLS, and the short term interest rate is from the Fed's FRED database.

Table 3.3: Posterior Distributions

Name	Description	Prior Mean	Mean	Mode	90% HPD interval	
η	Elasticity of substitution b/t fuel and core consumption	0.20	0.14	0.14	0.14	0.14
h	Habit persistence in consumption	0.50	0.65	0.66	0.62	0.67
κ	Interest rate channel strength	0.50	0.57	0.56	0.54	0.60
$\mu_{c^\star,do}$	Effect of oil production growth on oil global economic activity (GEA)	0.096	-0.01	-0.01	-0.02	0.00
$\mu_{o,do}$	Effect of oil production growth on real price of oil	-0.066	-0.02	-0.02	-0.03	-0.02
$\mu_{oc^\star}$	Effect of GEA on oil price	0.124	0.17	0.15	0.16	0.17
ω_e	Policy response to exchange rate	0.00	0.09	0.09	0.08	0.09
ω_π	Policy response to inflation	2.00	1.87	1.85	1.83	1.90
ω_y	Policy response to output gap	0.30	0.26	0.26	0.26	0.26
ϕ_h	Price rigidity for domestic goods	0.75	0.81	0.81	0.80	0.82
ϕ_l	Wage rigidity	0.75	0.75	0.74	0.73	0.77
ϕ_m	Price rigidity for imported goods	0.75	0.67	0.68	0.66	0.68
σ_l	inverse elasticity of labor supply	1.00	1.08	1.09	1.07	1.10
θ	Elasticity of substitution b/t home and foreign produced goods	0.50	0.73	0.73	0.73	0.74
ϱ	Elasticity of the upward slopping supply of international funds	0.005	0.004	0.003	0.003	0.004
ω	Elasticity of substitution b/t oil and labor inputs in production.	0.20	0.22	0.22	0.22	0.23
ξ_h	Price indexation for domestic goods	0.50	0.22	0.22	0.20	0.24
ξ_l	Wage indexation	0.50	0.32	0.34	0.30	0.33
ξ_m	Price indexation for imported goods	0.50	0.49	0.50	0.49	0.50
ρ_a	AR param. for TFP process	0.50	0.92	0.93	0.91	0.94
$\rho_{c^\star}$	AR param. for foreign consumption	0.50	0.85	0.85	0.83	0.87
$\rho_{do^\star}$	AR param. for oil supply growth	0.50	0.08	0.09	0.07	0.10
ρ_i	Nominal interest rate smoothing	0.75	0.09	0.10	0.06	0.11
$\rho_{i^\star}$	AR param. for foreign interest rate	0.50	0.64	0.64	0.63	0.66
$\rho_{o^\star}$	AR param. for real oil price	0.50	0.58	0.60	0.57	0.60
$\rho_{\pi^\star}$	AR param. for foreign inflation	0.50	0.57	0.59	0.56	0.59
ρ_ψ	AR param. oil price LOP gap	0.50	0.25	0.26	0.22	0.27
ρ_{tf}	AR param. for remittances	0.50	0.73	0.74	0.71	0.74
ρ_ζ	AR param. for labor supply shock	0.50	0.99	0.99	0.98	0.99

Barseghyan (2013) estimates a value of the smoothing parameter at about 0.70 in Armenia compared to 0.09 in our case.

Third, the strength of the impact of the central bank on the interest rate channel (κ) is equal to 0.57. This indicates that the ability of monetary policy to influence economy-wide interest rates is rather limited, and interestingly mirrors the degree of deposit and loan dollarization at about 60%.

The posterior estimates for the contemporaneous effects in the international oil market are in line with the priors. The only exception is the parameter $\mu_{c^\star do}$ that determines the impact of oil production growth on world economic activity in the current period. The value is negative, however, 90% confidence interval includes

zero.

The estimate of the autoregressive parameter of the law-of-one-price gap (LOP gap) is rather low at 0.25, indicating low persistence in the deviation of the local fuel price index from international energy prices.

4.2 Impulse Responses

We now look at the impulse responses of the key variables to the shocks of interest.

First, Figure 3.2 illustrates the dynamics associated with the monetary transmission channel. A positive innovation to the short-term policy interest rate (i_p) (monetary policy tightening) results in increased policy rate that returns to the steady-state value in 3-4 quarters. Given the low estimate of the policy smoothing parameter (ρ_i), such a response is not surprising. The response of the real variables, on the other hand, is much more persistent, lasting 10-12 quarters; output, consumption, inflation rate, and trade variables decline. The exchange rate appreciates in the short-term but overshoots before it returns to its steady-state value. The responses are consistent with the standard New Keynesian monetary policy transmission channel. Inflation response is instant and not very persistent. This is not surprising since we do not have some of the key model features discussed in Christiano et al. (2005) to allow for the delayed, inertial response of inflation.

Figures 3.3 to 3.5 display the reaction of the key macroeconomic variables to different types of oil shocks. A few interesting observations can be made.

First, oil supply shocks have a quantitatively small effect on all variables given the relatively modest estimate of the standard error of the shock associated with world oil production growth. This agrees with the findings in the recent strand of literature for developed economies that emphasizes the endogeneity of world oil prices and the structural sources of oil increases (Kilian, 2014, 2009a, 2008a). This is also consistent with out findings for Georgia and Armenia from the SVAR model with an international oil market in chapter 2.

Second, the response of the key variables to each type of oil shock is different. If we concentrate on output, consumption and inflation, we see that shocks due to increased global economic activity results leads to increased domestic GDP and consumption, and quantitatively very small decline in inflation, but shocks due to oil-market-specific demand shocks have negative impact on output initially and negative impact on consumption and positive impact on inflation. This is also similar to the effect observed estimated in the SVAR modeled for the Georgian economy mentioned above. We can also see that the response of monetary policy to these two shocks is also rather different.

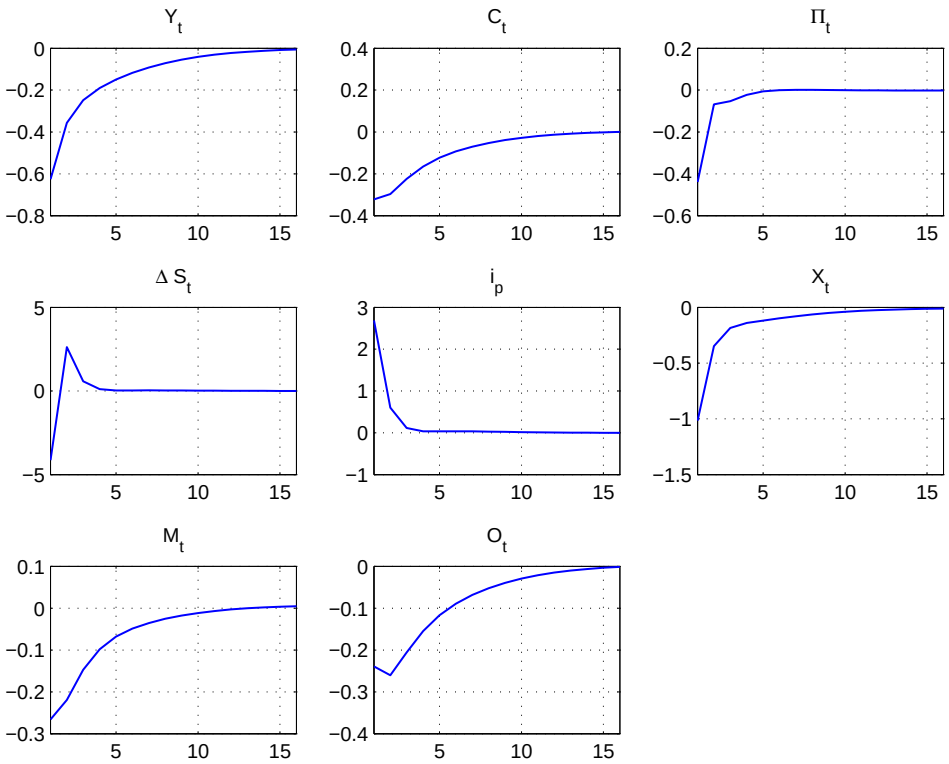

Figure 3.2: Impulse responses to 1 SD monetary policy shock, in percent, QoQ, @ar. Variables: Real GDP, real consumption, headline inflation, exchange rate depreciation, policy interest rate, real exports, real imports, oil imports.

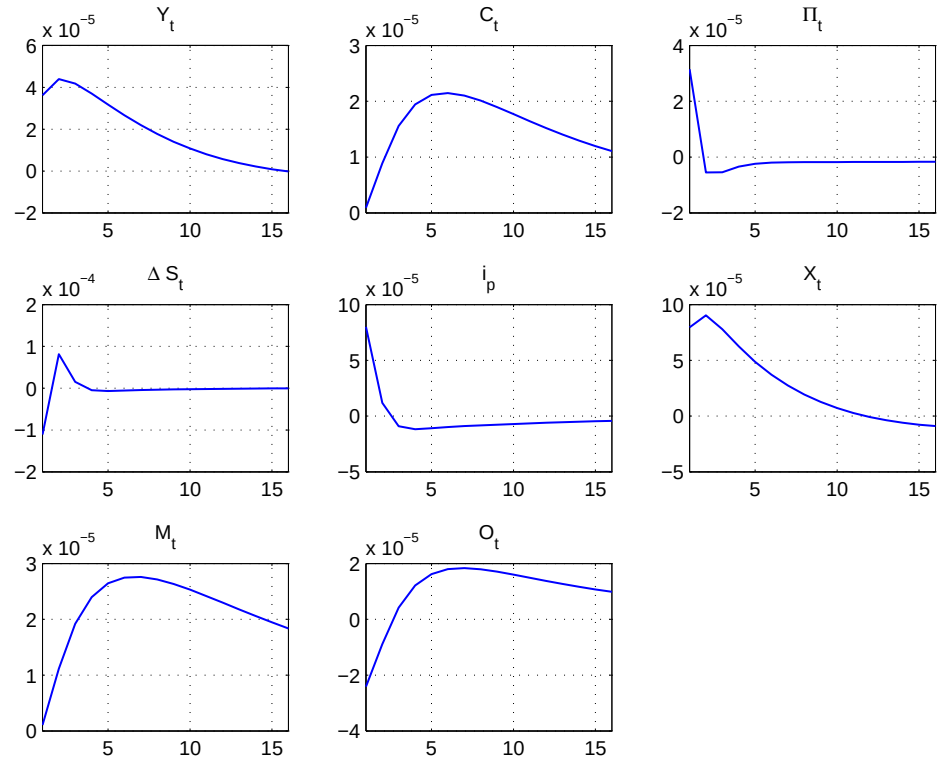

Figure 3.3: Impulse responses to 1 SD oil supply shock, in percent, QoQ, @ar. Variables: Real GDP, real consumption, headline inflation, exchange rate depreciation, policy interest rate, real exports, real imports, oil imports.

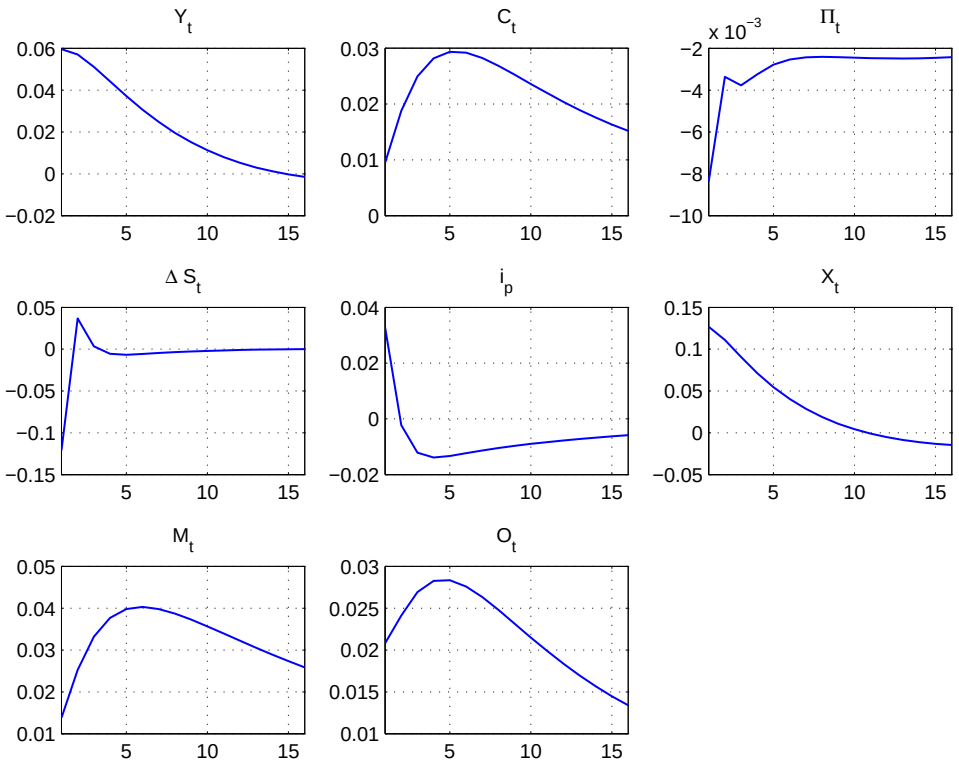

Figure 3.4: Impulse responses to 1 SD world economic activity shock, in percent, QoQ, @ar. Variables: Real GDP, real consumption, headline inflation, exchange rate depreciation, policy interest rate, real exports, real imports, oil imports.

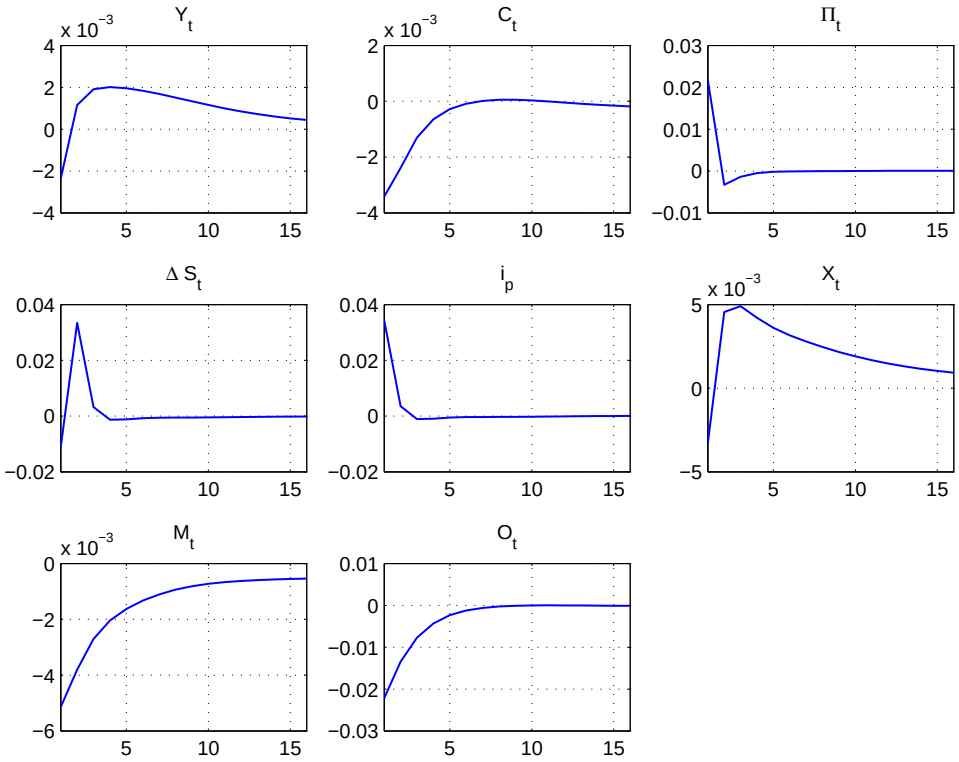

Figure 3.5: Impulse responses to 1 SD oil-market-specific demand shock, in percent, QoQ, @ar. Variables: Real GDP, real consumption, headline inflation, exchange rate depreciation, policy interest rate, real exports, real imports, oil imports.

5 Conclusion

We study the impact of oil price fluctuations on oil-importing developing economies focusing on Georgia as an example of a small open economy. Our objective is to understand the role of oil price jumps in the context of endogeneity of oil prices to global economic activity and the specificities of *developing* economies.

We argue that differences in development translate into differences in the transmission channels through which the oil shocks propagate. Frankel (2011)argues that less developed economies are characterized by less developed institutions and higher degrees of market volatility. The former is manifested in less credible monetary policy, less efficient fiscal system, less competitive banking system, and imperfect financial markets. The volatility usually stems from higher exposure to international influences in trade, more pronounced supply and demand shocks in the goods markets, and global financial market influences.

We concentrate on monetary policy, usually considered an important factor for the transmission of oil shocks for developed countries. Less credible monetary policy and weak interest rate channels in developing economies imply that the role of monetary policy to moderate the effects of oil shocks is most likely less pronounced and less efficient. Nevertheless, it is interesting to examine the reaction of the central bank to oil price shocks, and the role of weak interest rate channels.

We study this question in an estimated DGSE model for Georgia, taking the specificities of the monetary policy into consideration. In particular, we use our structural model to estimate the effects of responses of key macroeconomic variables to different types of shocks (including the different types of oil shocks). We estimate the key parameters for monetary policy rule and the corresponding response of policy rate to shocks. We analyze the role of weak interest rate channel in the context of oil price shocks.

The DGSE model used in the text is a small open economy version of a canonical New Keynesian model augmented with an oil sector. Oil is consumed by households and used by firms as a factor of production. This setting (even in a closed economy) implies the breakdown of divine coincidence and the trade-off between inflation and output stabilization (Natal, 2012). The model is modified to allow for a richer international oil market. In particular, we are able subject the artificial economy to shocks that may be interpreted as oil supply, world economic activity, and oil-market-specific demand shocks similar to the strand of literature reviewed in Kilian (2014). The model also allows for a limited ability of the central bank to affect the economy-wide effective interest rate, reflecting the weak interest rate channel arising from high dollarization or low monetary policy credibility. All the additional characteristics of the model are parametrized in a simple setting and the parameters

are estimated with Bayesian methods.

Parameter estimates indicate the following. First, the values of the parameters associated with the monetary transmission channel (nominal price and wage rigidities, price and wage indexation, Taylor rule parameters) are in line with findings from studies on other developed and developing countries. The only aberration is the policy interest rate smoothing parameter, that is significantly lower than that found in similar studies. Second, the estimate of the strength of the impact of the central bank on the interest rate channel indicates that the ability of monetary policy to influence economy-wide interest rates is somewhat limited but still quantitatively significant. Third, the posterior estimates for contemporaneous effects in the international oil market are consistent with findings from the SVAR literature (Kilian, 2014, 2009a).

The impulse responses to different types of oil shocks show the source of the increase in international oil prices matters even for a small, open, developing economy such as Georgia. First, oil supply shocks have a quantitatively small effect on all variables in the domestic economy. Second, the reaction of key macroeconomic variables to different types of shocks is different. Third, monetary policy responds indirectly to oil price increases through its reaction to inflation, output gap, and exchange rate, and the responses are different depending on the structural shock associated with the increase in oil price.

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3.A Model Equations and Variables

What follows is the summary of all model equations for both home country and external sector. The equations are written in nonlinear form and are entered in the solution software (Dynare) also in nonlinear format. This helps us to avoid errors from manual log-linearisation and makes modifying and extending the structural equations easier. t+1 time index indicates the expected value of the corresponding variable.

Model

Consumers

$$
\begin{aligned}
C_{Ht} &= (1-\gamma)(PR_{Ht}/PR_{Zt})^{-\theta} Z_t \\
C_{Ft} &= \gamma(PR_{Ft}/PR_{Zt})^{-\theta} Z_t \\
O_{Ct} &= \delta PR_{Ot}^{-\eta} C_t \\
Z_t &= (1-\delta) PR_{Zt}^{-\eta} C_t \\
1 &= \beta \frac{(C_t - hC_{t-1})}{(C_{t+1} - hC_t)} \frac{(1+i_t)}{\Pi_{t+1}(1+g_y)} \\
1 &= \beta \frac{(C_t - hC_{t-1})}{(C_{t+1} - hC_t)} \frac{\Delta S_{t+1}}{\Pi_{t+1}(1+g_y)} (1+i_t^{\star}) \bar{\Theta} \exp(-\varrho(b_t^{\star} - \bar{b^{\star}}))
\end{aligned}
$$

Wage Dynamics

$$
\begin{aligned}
(W_t^{Opt})^{1+e_L\sigma_L} \chi_{1t}^W &= \frac{e_L}{e_L - 1}(1+\sigma_L)\chi_{2t}^W \\
\chi_{1t}^W &= \frac{L_{Ht} W_t^{e_L} \Pi_t^{e_L - 1}}{(C_t - hC_{t-1})} + \phi_L \beta (\Pi_t^{\xi_L} \bar{\Pi_t}^{1-\xi_L})^{1-e_L} \Pi_t^{e_L - 1} \chi_{1,t+1}^W \\
\chi_{2t}^W &= L_{Ht}^{1+\sigma_L} (W_t \Pi_t)^{e_L + e_L\sigma_L} \zeta_t + \phi_L \beta \left(\frac{\Pi_t}{\Pi_t^{\xi_L} \bar{\Pi}^{1-\xi_L}} \right)^{e_L + e_L\sigma_L} \chi_{2,t+1}^W \\
W_t^{Opt} &= \left(\frac{(W_t \Pi_t)^{1-e_L} - \phi_L (W_{t-1} \Pi_{t-1}^{\xi_L} \bar{\Pi}^{1-\xi_L})^{1-e_L}}{1-\phi_L} \right)^{\frac{1}{1-e_L}} \\
\zeta_t &= \zeta_{t-1}^{\rho_\zeta} \bar{\zeta}^{1-\rho_\zeta} \exp(\epsilon_{\zeta t})
\end{aligned}
$$

Price Dynamics

$$P_{Ht}^{Opt} PR_{H,t-1} \xi_{1t}^{H} = e_H/(e_H - 1)\chi_{2t}^{H}$$
$$\chi_{1t}^{H} = \frac{Y_{Ht}}{(C_t - hC_{t-1})} \frac{\Pi_{Ht}^{e_H}}{\Pi_t} + \phi_H \beta \frac{(\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{1-e_H} \Pi_{Ht}^{e_H}}{\Pi_t} \chi_{1,t+1}^{H}$$

$$\chi_{2t}^{H} = \frac{Y_{Ht} RMC_t \Pi_{Ht}^{e_H}}{(C_t - hC_{t-1})} + \phi_H \beta (\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{-e_H} \Pi_{Ht}^{e_H} \chi_{2,t+1}^{H}$$
$$P_{Ht}^{Opt} = \left(\frac{\Pi_{Ht}^{1-e_h} - \phi_H (\Pi_{H,t-1}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{1-e_H}}{1 - \phi_H} \right)^{\frac{1}{1-e_H}}$$
$$L_{Ht} = (1-\alpha) RMC_t \frac{W_t^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha PR_{Ot}^{1-\omega}} P_{Ht}^{d} Y_{Ht}$$
$$O_{Ht} = \alpha RMC_t \frac{PR_{Ot}^{-\omega}}{(1-\alpha) W_t^{1-\omega} + \alpha PR_{Ot}^{1-\omega}} P_{Ht}^{d} Y_{Ht}$$
$$P_{Ht}^{d} = (1-\phi_H)(P_{Ht}^{Opt}/\Pi_{Ht})^{-e_H} + \phi_H \Pi_{Ht}^{e_H} (\Pi_{Ht}^{\xi_H} \bar{\Pi}^{1-\xi_H})^{-e_H} P_{H,t-1}^{d}$$
$$RMC_t = A_{Ht}^{-1} ((1-\alpha) W_t^{1-\omega} + \alpha PR_{Ot}^{1-\omega})^{1/(1-\omega)}$$
$$A_{Ht} = A_{H,t-1}^{\rho_A} \bar{A_H}^{1-\rho_A} \exp(\epsilon_{At})$$

Domestic Importers

$$P_{Mt}^{Opt} PR_{F,t-1} \chi_{1t}^{M} = e_M/(e_M - 1)\chi_{2t}^{M}$$
$$\chi_{1t}^{M} = \frac{C_{Ft}}{(C_t - hC_{t-1})} \frac{\Pi_{Ft}^{e_M}}{\Pi_t} + \phi_M \beta \frac{(\Pi_{Ft}^{\xi_M} \bar{\Pi}^{1-\xi_M})^{1-e_M} \Pi_{Ft}^{e_M}}{\Pi_t} \chi_{1,t+1}^{M}$$
$$\chi_{2t}^{M} = \frac{C_{Ft}}{(C_t - hC_{t-1})} \Pi_{Ft}^{e_M} Q_t + \phi_M \beta (\Pi_{Ft}^{\xi_M} \bar{\Pi}^{1-\xi_M})^{-e_M} \Pi_{Ft}^{e_M} \chi_{2,t+1}^{M}$$
$$P_{Mt}^{Opt} = \left(\frac{\Pi_{Ft}^{1-e_M} - \phi_M (\Pi_{F,t-1}^{\xi_M} \bar{\Pi}^{1-\xi_M})^{1-e_M}}{1 - \phi_M} \right)^{\frac{1}{1-e_M}}$$
$$P_{Mt}^{d} = (1-\phi_M)(P_{Mt}^{Opt}/\Pi_{Ft})^{-e_M} + \phi_M \Pi_{Ft}^{e_M} (\Pi_{Ft}^{\xi_M} \bar{\Pi}^{1-\xi_M})^{-e_M} P_{M,t-1}^{d}$$
$$PR_{Ft}/PR_{F,t-1} = \Pi_{Ft}/\Pi_t$$

Relative Prices

$$
\begin{aligned}
&PR_{Ht}/PR_{H,t-1} = \Pi_{Ht}/\Pi_t \\
&PR_{Zt} = (\gamma PR_{Ft}^{1-\theta} + (1-\gamma)PR_{Ht}^{1-\theta})^{1/(1-\theta)} \\
&PR_{Ot} = Q_t PR_{O^\star t}\psi_t \\
&\psi_t = \psi_{t-1}^{\rho_\psi}\exp(\epsilon_{\psi t}) \\
&Q_t/Q_{t-1} = \Delta S_t \Pi_t^\star/\Pi_t \\
&(\delta PR_{Ot}^{1-\eta} + (1-\delta)PR_{Zt}^{1-\eta})^{1/(1-\eta)} = 1
\end{aligned}
$$

Aggregate Equilibrium

$$
\begin{aligned}
&Y_{Ht} = C_{Ht} + \gamma^\star((e_M-1)/e_M)^{-\eta_\star}(PR_{Ht}/Q_t)^{-\eta^\star}C_t^\star \\
&PR_{Yt}Y_t = C_t + PR_{Xt}X_t - PR_{Mt}M_t - Q_t TF_t \\
&PR_{Yt} = PR_{Xt}^{\bar{X}/\bar{Y}}PR_{Mt}^{-\bar{M}/\bar{Y}} \\
&PR_{Xt}X_t = PR_{Ht}\gamma^\star(PR_{Ht}/Q_t(e_M-1)/e_M)^{-\eta^\star}C_t^\star \\
&PR_{Xt} = PR_{Ht} \\
&TF_t = TF_{t-1}^{\rho_{TF}}(\bar{TF}(C_t^\star/\bar{C}^\star)^{\mu_c})^{1-\rho_{TF}}\exp(\epsilon_{TFt}) \\
&PR_{Mt}M_t = PR_{Ft}C_{Ft} + PR_{Ot}O_t \\
&PR_{Mt} = PR_{Ft}^{\bar{C_F}/\bar{M}}PR_{Ot}^{1-\bar{C_F}/\bar{M}} \\
&O_t = O_{Ct} + O_{Ht} \\
&\frac{b_t^\star}{(1+i_t^\star)\bar{\Theta}\exp(-\varrho(b_t^\star - \bar{b}^\star))} - \frac{b_{t-1}^\star \Delta S_t}{\Pi_t(1+g_y)}\frac{PR_{X,t-1}X_{t-1}}{PR_{Xt}X_t} = 1 - \frac{PR_{Mt}M_t - Q_t TF_t}{PR_{Xt}X_t}
\end{aligned}
$$

Policy Rule

$$
\begin{aligned}
&1+i_t^p = (1+i_{t-1}^p)^{\rho_i}(\bar{\Pi}(1+g_y)/\beta(\Pi_t/\bar{\Pi})^{\omega_\Pi}(Y_t/Y_{t-1})^{\omega_Y}(\Delta S_t/\bar{\Delta S})^{\omega_S})^{1-\rho_i}\nu_t \\
&1+i_t = (1+i_t^p)^\kappa((1+i_{t-1}^\star)\Delta S_t\bar{\Theta}\exp(-\varrho(b_{t-1}^\star - \bar{b}^\star)))^{1-\kappa}\exp\{e_t^d\} \\
&R_t = (1+i_t)/\Pi_{t+1} \\
&\nu_t = \nu_{t-1}^{\rho_\nu}\exp(\epsilon_{\nu t})
\end{aligned}
$$

External Sector

$$
\begin{aligned}
dO_t^\star &= (dO_{t-1}^\star)_{do^\star}^{\rho} \exp\left(\epsilon_{do^s tar}\right) \\
C_t^\star &= (C_{t-1}^\star)^{\rho_{C^\star}} (\bar{C}^\star)^{1-\rho_{C^\star}} (dO_t^\star)^{\mu_{C^\star do}} \exp\left(\epsilon_{C^\star t}\right) \\
PR_{O^\star t} &= PR_{O^\star,t-1}^{\rho_{O^\star}} \bar{PR}_{O^\star}^{1-\rho_{O^\star}} (C_t^\star/\bar{C}^\star)^{\mu_{OC^\star}} (dO_t^\star)^{\mu_{OdO}} \exp\left(\epsilon_{O^\star t}\right) \\
\Pi_t^\star &= (\Pi_{t-1}^\star)^{\rho_{\Pi^\star}} (\bar{\Pi}^\star)^{1-\rho_{\Pi^\star}} exp(\epsilon_{\Pi^\star t}) \\
(1+i_t^\star) &= (1+i_{t-1}^\star)^{\rho_{i^\star}} (1+\bar{i^\star})^{1-\rho_{i^\star}} \exp(\epsilon_{i^\star t})
\end{aligned}
$$

Model Variables

Table A3.1: Description of Model Variables (Part 1)

Name	Description
A_H	TFP process for domestic intermediate producers.
$b^\star$	Domestic claims on foreign bonds relative to nominal exports.
C	Consumption (includes oil products).
C_F	Consumption of imported goods excluding oil.
C_H	Consumption of home-produced goods excluding oil.
$C^\star$	Foreign output.
$dO^\star$	World oil production growth.
i	Nominal interest rate.
i^p	Policy rate.
$i^\star$	Foreign nominal interest rate.
L_H	Labor supply.
M	Real imports.
O	Real oil imports.
O_C	Oil used for consumption.
O_H	Oil used for production.
P_H^{Opt}	Optimal price set by domestic intermediate producers relative to previous period price of intermediate goods.
P_M^{Opt}	Optimal price set by domestic importers relative to previous period price of imported goods.
PR_F	Relative price of export goods.
PR_H	Relative price of home-produced good.
PR_M	Relative price of import goods.
PR_O	Relative price of imported oil.
$PR_O^\star$	Relative world oil price (relative to USD).
PR_X	Relative price of exports.
PR_Y	Relative GDP deflator.
PR_Z	Relative price of consumption basket excluding oil.

All real variables or relative prices are normalized by domestic CPI unless noted otherwise.

Table A3.2: Description of Model Variables (Part 2)

Name	Description
P_H^d	Price dispersion for domestic intermediate producers.
P_M^d	Price dispersion for domestic importers.
Q	Real exchange rate: Foreign CPI times nominal exchange rate over the domestic CPI.
R	Real interest rate: nominal interest rate minus expected CPI inflation.
RMC	Real marginal cost.
TF	Transfer to domestic economy.
W	Real wage.
W^{Opt}	Optimal wage set in current period relative to previous period aggregate wage rate.
X	Real exports.
Y	GDP.
Y_H	Output of aggregated domestic intermediate sector.
Z	Consumption basket excluding oil.
ΔS	Nominal exchange rate depreciation.
ζ	Preference shock.
ν	Monetary policy shock.
Π	CPI inflation (gross).
Π_H	Inflation of home-produced goods.
Π_F	Inflation of imported foreign-produced goods.
$\Pi^\star$	Foreign inflation.
χ_i^H	Philips curve auxiliary variable for domestic intermediate goods
χ_i^M	Philips curve auxiliary variable for imported goods
χ_i^W	Wage Philips curve auxiliary variable
χ_2^H	Philips curve auxiliary variable for domestic intermediate goods
χ_2^M	Philips curve auxiliary variable for imported goods
χ_2^W	Wage Philips curve auxiliary variable
ψ	Oil price law-of-one-price gap shock.

All real variables or relative prices are normalized by domestic CPI unless noted otherwise.