Essays on Commodities and International Macroeconomic Interactions

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Trinity Term 2018

Submitted for the degree of Doctor of Philosophy in Economics

Abstract

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This thesis introduces commodities into otherwise standard closed economy or open economy macro models. Chapter 1 sheds light on the fact that as trading in commodity derivatives tied to commodity prices has increased massively since the 2000s, they have begun to act as an asset class in recent years. It shows that financial intermediaries' investments in commodities play an important role in the recent reduction in the impacts of commodity price shocks on the economy. Chapter 2 adds commodities and different commodity trade structures of countries to a standard two-country model. It shows that U.S. business cycle comovements with commodity-exporting countries are stronger than those with commodity-importing countries and that the model produces better international business cycle statistics between the U.S. and commodity-exporting countries compared to the standard model. These results imply that the two elements should be considered to properly analyse international macroeconomic interactions between the U.S. and commodity-exporting countries. Chapter 3 studies international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries. The chapter first empirically shows that the shocks have stronger effects on commodity-exporting countries than commodity-importing countries, and then augments a standard three-country model to include commodities and different commodity trade structures of countries. Consistently with the empirical evidence, in the model an expansionary monetary policy shock to the U.S. increases aggregate output of commodity-exporting countries by more than that of commodity-importing countries. This is because the increased U.S. aggregate demand triggered by the shock leads to rises in its demand for commodities and real commodity prices, and thus exports of commodity-exporting countries go up by more than those of commodity-importing countries.

Acknowledgement

First of all, I am very grateful to my supervisors, Andrea Ferrero and David Vines. Their guidance, advice, encouragement and support have been invaluable in developing my work. Without them, it would have been impossible to finish my thesis in a relatively short period. I am very fortunate to have had the opportunity to learn from them and to work with them.

I have benefited from several other people in writing this thesis as well. In particular, I am indebted to Guido Ascari, John Muellbauer and Rick van der Ploeg who gave me valuable comments and suggestions. I would also like to thank Xiyu Jiao and Segye Shin with whom I frequently discussed my thoughts.

Last but not least, I would like to thank my parents, my wife and two sons for their patience and support during my study. I am especially grateful to my wife, Kayeung, whose love and encouragement have been invaluable for the writing of this thesis.

Word count

Approximately 51,450 words (147 pages $\times$ 350 words on typical page)

Contents

Introduction

This thesis consists of three chapters. Although each chapter has an independent research question and methodology, they are related by a common theme of commodities, such as oil, metal, wheat, etc.

Commodities have peculiar features. They are consumed as well as used as inputs in production in nearly all sectors. Other goods are only consumed or only used as inputs in production in a specific sector. Accordingly, changes in commodity prices have greater impacts on the economy than changes in prices of other goods, since changes in commodity prices affect both households and firms in the economy. Importance of commodity prices to the economy have been confirmed by many studies. For instance, Hamilton (1983) shows that oil price shocks contributed to almost every postwar recession in the U.S. Thus, many macroeconomists have regarded changes in commodity prices as a critical source of economic fluctuations and one that can affect many countries simultaneously (Blanchard and Galí, 2007). Taking this point into account, this thesis analyses how commodities or their prices interact with macroeconomic variables in a closed or open economy.

Chapter 1 studies the role of commodities as an asset class in the recent reduction in the impacts of commodity price shocks on the economy. Specifically, it analyses whether financial intermediaries' investment in commodities can play an important role in the recently declined effects of commodity price shocks on the economy.

Blanchard and Galí (2007) and Segal (2011) discuss why the effects of commodity prices, especially oil prices, on the economy have reduced since the 2000s. They provide several reasons for this, such as lack of concurrent adverse shocks, smaller share of oil in production, more flexible labour markets and improvements in monetary policy in the 2000s compared to before. In addition, since trading in commodity derivatives has increased massively since the 2000s, commodities have begun to act as an asset class in recent years, which may contribute to the recently reduced effects of commodity prices on the economy as well.

To examine whether commodities as an asset class have contributed to the recent reduction in the impacts of commodity price shocks on the economy, I set out a model with financial frictions and financial intermediaries investing in assets tied to both commodities and capital by extending the model of Bernanke, Gertler and Gilchrist (1999). In the model, commodities are also included in consumption and the production function. I simulate the responses of the macroeconomic variables to a negative commodity price shock, and compare them to those in a model that omits financial intermediaries' investment in commodities to see whether commodities as an asset class play a role in the reduced impacts of commodity price shocks. The simulation results show that the responses in the model to a negative commodity price shock are weaker than the responses in a model in which financial intermediaries only hold capital. A fall in commodity prices leads not only to an increase in the returns to financial intermediaries' investment in assets tied to capital but also a fall in the returns to their investment in commodities. Accordingly, their net worth rises by less compared to a model with financial intermediaries holding assets only associated with capital. The smaller increase in the net worth of financial intermediaries leads to a smaller rise in their investment in capital, which brings about a smaller increase in output compared to a model in which financial intermediaries only invest in capital. Hence, commodities as an asset class might explain the recently reduced impacts of commodity price shocks on the economy according to this analysis.

Chapter 2 analyses international business cycles between the U.S. and commodity-exporting countries. The chapter first shows that U.S. business cycle comovements with commodity-exporting countries are different from those with commodity-importing countries. Then, it constructs a two-country model that can replicate the international business cycles between the U.S. and commodity-exporting countries.

Output growth in the U.S., a commodity-importing country, raises its demand for imports of commodities and thus commodity prices. This benefits commodity-exporting countries, but has adverse effects on commodity-importing countries. Hence, in the data GDPs of commodity-exporting countries are more strongly correlated with U.S. GDP than those of commodity-importing countries. However, international business cycles between the U.S. and commodity-exporting countries have not yet been separately considered in the literature, although they are significantly different from those between the U.S. and commodity-importing countries.

To address this shortcoming in the literature, this chapter introduces commodities and different commodity trade structures of countries into a standard two-country model. Differently from standard models, in the model, the home country, the U.S., does not produce commodities and imports commodities, while the foreign country, commodity-exporting countries, produces commodities and exports commodities. Commodities are included in the consumption basket as a complement to noncommodity goods, and used as inputs in the production of tradable goods.

The model produces international business cycle statistics in response to productivity shocks which are closer to the data compared to a standard model. In particular, the model produces higher output correlation and lower consumption correlation than the standard model. Moreover, the model yields output correlation that exceeds the consumption correlation, which is consistent with the ranking in the data. On the contrary, standard models typically yield the opposite prediction, which is referred in the literature as the "consumption correlation puzzle."[1] Therefore, adding commodities with consideration for different commodity trade structures of countries helps mitigate the consumption correlation puzzle. Commodity consumption and complementarity between commodities and noncommodity goods in consumption[2] play key roles in generating this result.

With regards to the output correlation, positive productivity shocks to the home country increase home aggregate output and consumption. Home demand for imports of commodities and foreign tradable goods rises, which leads to increases in the real prices of foreign tradable goods and commodities. The increased real price of foreign tradable goods causes a fall in home consumption of foreign tradable goods. Despite a rise in the real commodity price, however, home commodity consumption increases thanks to the complementarity between

[1] Since Backus, Kehoe and Kydland (1995) name the puzzle the "quantity anomaly" and the puzzle was first presented in Backus, Kehoe and Kydland (1992), it is alternatively called the "quantity anomaly" or the "BKK puzzle."

[2] If there is complementarity between commodities and noncommodity goods, consumption of commodities can rise in response to an increase in commodity prices when consumption of noncommodity goods go up sufficiently. There are many empirical studies showing that they are complements (see Cooper, 2003; Bodenstein, Erceg and Guerrieri, 2011; etc.).

commodities and noncommodity goods in consumption. Therefore, in the model there is a larger positive spillover to the foreign country compared with standard models, which raises the output correlation.

Commodity consumption, which is not in standard models, together with the complementarity of commodity consumption with noncommodity consumption is important in lowering the consumption correlation. Specifically, when a positive productivity shock hits the home tradable sector, home commodity consumption and the real commodity price increase, and the real price of home tradable goods falls. Foreign noncommodity consumption goes up thanks to a fall in the real price of home tradable goods. Foreign commodity consumption rises as well due to the complementarity in spite of a rise in the real commodity price. Hence, home and foreign commodity consumptions are positively correlated with respect to productivity shocks to the tradable sector. On the contrary, home and foreign commodity consumptions are negatively correlated with respect to productivity shocks to the nontradable sector. A positive productivity shock to the home nontradable sector brings about rises in home aggregate output and commodity consumption. The increase in home aggregate output leads to rises in the real prices of commodities and tradable goods produced in both countries. Foreign noncommodity consumption drops due to the increased real prices of tradable goods. Foreign commodity consumption falls as well owing to the complementarity and the increased real commodity price. The negative correlation between home and foreign commodity consumptions with respect to productivity shocks to the nontradable sector enables the correlation between home and foreign commodity consumptions to be smaller than that between home and foreign noncommodity consumptions. Therefore, the consumption correlation in the model becomes lower than that in the standard model.

From the analysis, the chapter concludes that adding commodities to open economy macro models with consideration for different commodity trade structures of countries helps to explain key features of international business cycles between the U.S. and commodity-exporting countries.

Chapter 3 studies international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries. I first show empirically that the shocks have stronger effects on commodity-exporting countries than commodity-importing countries. Then, I rationalise this empirical finding through a three-country model.

According to some studies such as Barsky and Kilian (2001), U.S. monetary policy has significant effects on commodity prices. Since changes in commodity prices affect commodity-exporting and commodity-importing countries differently (Bodenstein, Erceg and Guerrieri, 2011), international transmissions of U.S. monetary policy shocks to the two groups may be different as well.

To investigate the empirical mechanism of how U.S. monetary policy shocks affect outputs of commodity-exporting and commodity-importing countries differently, an econometric methodology is used. This analysis shows that the positive effects of an expansionary U.S. monetary policy shock on outputs of commodity-exporting countries tend to be stronger than those on outputs of commodity-importing countries. A rise in commodity prices and a larger increase in exports of commodity-exporting countries than those of commodity-importing countries in response to the shock may explain the stronger effects on outputs of commodity-exporting countries than commodity-importing countries of the shock.

In order to analyse international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries, I add commodities with consideration for different commodity trade structures of countries to a standard three-country dynamic stochastic general equilibrium model. In the model, although country A (the U.S.) produces commodities, its production of commodities is not enough to meet domestic demand for commodities. Thus, it always imports commodities from commodity-exporting countries. Country B (commodity-importing countries) is the same as country A. Country C (commodity-exporting countries) produces commodities to meet domestic demand for commodities and the other countries' demand for imports of commodities, and thus always exports commodities.

Simulation results show that the responses of the model to an expansionary monetary policy shock in the U.S. capture the empirical mechanism well. Specifically, the increased aggregate demand in the U.S. triggered by the shock leads to rises in its demand for commodities and real commodity prices. Hence, commodity-exporting countries' exports of commodities to the U.S. increase, which leads to a larger increase in exports of commodity-exporting countries than those of commodity-importing countries. Consequently, the aggregate output of commodity-exporting countries goes up by more compared to that of commodity-importing countries.

A common conclusion of the three chapters, in spite of independent research questions and methodologies across each of the chapters, is that adding commodities to macro models is useful in explaining various macroeconomic phenomena: the recent reduction in the effects of commodity price shocks on the economy, international business cycles between the U.S. and commodity-exporting countries, and international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries. In particular, different commodity trade structures of countries as well as commodities should be considered to properly analyse international macroeconomic interactions.

References

Backus, D., P. Kehoe, and F. Kydland (1992). International real business cycles. *Journal of Political Economy 101*, 745–775.

Backus, D., P. Kehoe, and F. Kydland (1995). International business cycles: Theory and evidence. *Frontiers of Business Cycle Research (Princeton: Princeton University Press)*, 331–356.

Barsky, R. B. and L. Kilian (2001). Do we really know that oil caused the great stagflation? A monetary alternative. NBER Working Paper Series 8389.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics 1*, 1341–1393.

Blanchard, O. J. and J. Galí (2007). The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? NBER Working Paper No. 13368.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2011). Oil shocks and external adjustment. *Journal of International Economics 83*, 168–184.

Cooper, J. (2003). Price elasticity of demand for crude oil: Estimates for 23 countries. *OPEC Review 27*, 1–8.

Hamilton, J. D. (1983). Oil and the macroeconomy since world war II. *Journal of Political Economy 91*, 228–248.

Segal, P. (2011). Oil price shocks and the macroeconomy. *Oxford Review of Economic Policy 27*, 169–185.

I. How the Financial Market Can Dampen the Effects of Commodity Price Shocks

Abstract

This chapter constructs a model with financial frictions and financial intermediaries that own two assets tied to capital and commodities, and uses this to analyse the role of commodities as an asset class in the recent reduction in the impacts of commodity price shocks. Since financial intermediaries hold assets associated with both commodities and capital, their net worth depends on commodity prices as well. The simulation results of the model show that the responses of the economy to a negative commodity price shock are weaker than the responses in a model in which financial intermediaries only hold capital. This is because *ceteris paribus*, a negative commodity price shock decreases the net worth of financial intermediaries and their investment in capital, which partly offsets the positive effects of a negative commodity price shock.

1. Introduction

Although commodity prices (CPs) have been declining sharply and have almost halved since the second half of 2014, the economic conditions have not become better (see (a) in Figure 1). Why so? Is this because CPs have nothing to do with the economy, or because the effects of CPs on the economy have become weaker?

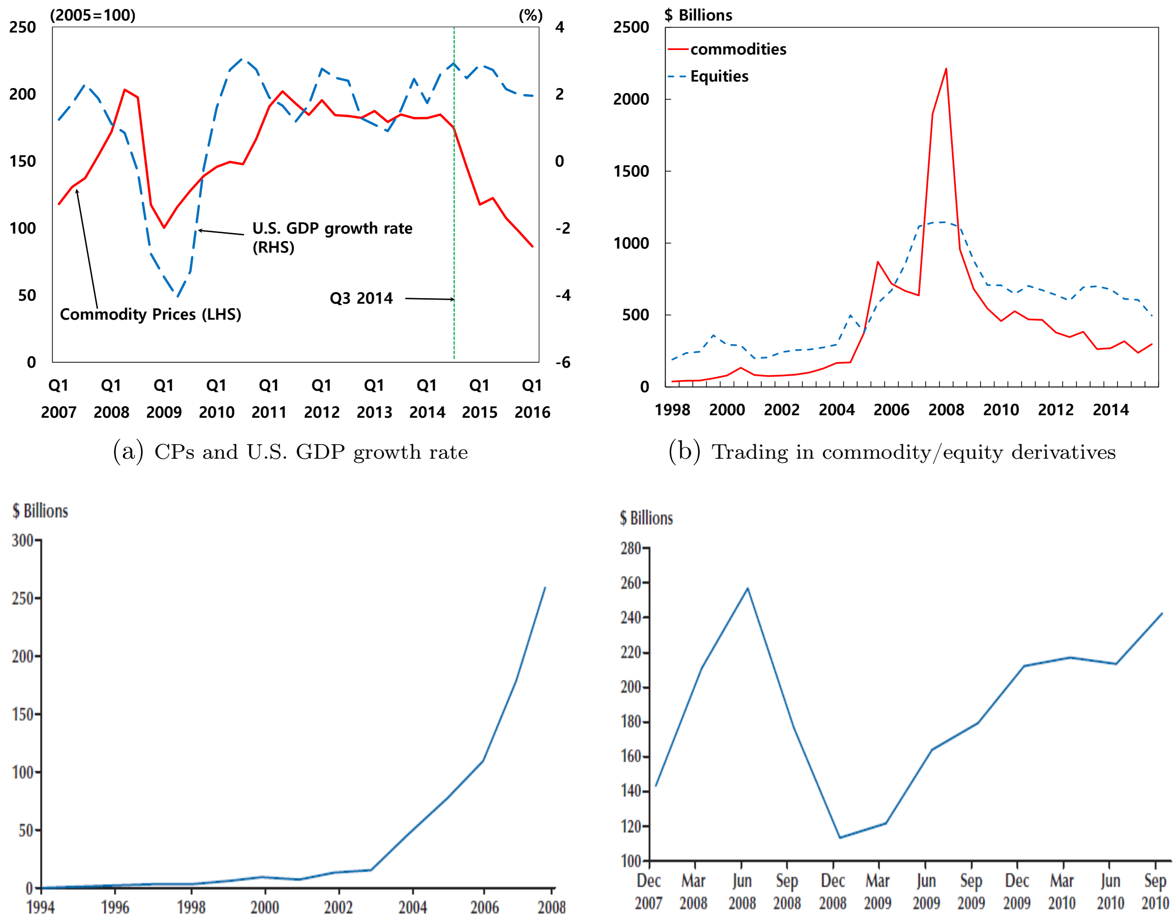
It is generally accepted that there is a negative relationship between CPs and the economy: when prices of commodities such as oil, metal, wheat, etc. fall, the economic effects of this are positive. This is because a fall in CPs decreases living costs and increases real income.

Moreover, firms using commodities as inputs to produce goods benefit from the low input prices and decreased marginal costs, and thus their output rises. For this reason, changes in CPs have been regarded by macroeconomists as a critical source of economic fluctuations.

In fact, many empirical studies conclude that CPs (especially, oil prices) have significant effects on macroeconomic variables. Hamilton (1983) presents evidence supporting the proposition that oil price shocks contributed to almost every U.S. recession over the period 1948-72. Using vector autoregressions (VARs), Burbidge and Harrison (1984), Rotemberg and Woodford (1996), Cuñado and Gracia (2003) and Leduc and Sill (2004) also show that an increase in oil prices brings about a fall in industrial production or output.

However, other literature using structural models provides evidence that energy price shocks have little effects on the economy. For example, Kim and Loungani (1992) include energy in the real business cycle (RBC) model with exogenous energy prices. They find that the inclusion of energy price shocks increases output volatility only modestly, which supports the views such as that of Tobin (1980) that the effects of energy price shocks on the economy are not important, since the share of energy in GNP is too small to generate big aggregate effects from energy price shocks. Dhawan and Jeske (2008) show similar results by extending the model of Kim and Loungani (1992). Krugman (2016) also argues that investment spending falls quickly when oil prices decrease sharply, since a lot of investment spending is tied to oil prices, and thus the relationship does not hold.

More importantly, according to some literature, the relationship between CPs and macroeconomic variables is insignificant or attenuated when using more recent data. Using VARs over 1970-83 and 1984-2006, Blanchard and Galí (2007) conclude that oil prices had much lower impact on inflation and output in the second period than they did in the first period. According to them, this result is due to lack of concurrent adverse shocks, smaller share of oil in production, more flexible labour markets and improvements in monetary policy during the second period. Segal (2011) also finds that the rises in oil prices during the last few years had little influence on the economy. This is due to the fact that since high oil prices no longer pass through to inflation, rises in oil prices do not increase prices, and thus interest rates do not need to respond to high oil prices, which causes the minimal impact on the economy. Darrat, Gilley and Meyer (1996) and Hooker (1996) also show similar estimation results.[1]



(a) CPs and U.S. GDP growth rate

(b) Trading in commodity/equity derivatives

(c) Commodity index fund investment

(d) Long positions of commodity futures index funds

Figure 1: Commodity prices and derivatives, and U.S. GDP growth rate

Notes: (b) is OTC trading and gross market vaules, (c) is year-end investment, and (d) is notional values. (c) and (d) are taken from Basu and Gavin (2011).

Sources: International Monetary Fund international financial statistics, Bank for International Settlements derivatives statistics, and Basu and Gavin (2011)

Setting the above literatures aside, as trading in commodity derivatives tied to CPs has increased massively since the 2000s,[2] they have begun to act as an asset class in recent years, which may contribute to the weakened relationship as well. For example, consider

[1] Differently from this literature, Kilian (2009) concludes that the reason why the recent increases in oil prices have not been followed by a U.S. recession is that the increases were due to strong demand for oil thanks to a booming world economy rather than oil supply disruptions.

[2] Since the 2000s, many financial intermediaries have added commodity derivatives as an asset class to their portfolios (see (b), (c) and (d) in Figure 1). There are two reasons for this according to Basu and Gavin (2011). The first reason is the search for higher yields. When the returns on safe assets are low, financial intermediaries tend to choose riskier assets. Second, they use commodity derivatives to hedge against equity risk due to the negative correlation between equity and commodity returns.

the framework of models with financial frictions and the costly state verification (CSV) approach developed by Bernanke, Gertler and Gilchrist (1999), henceforth BGG. Let financial intermediaries (FIs) be leveraged instead of entrepreneurs that are leveraged in BGG. This is because the massive recent increase in trading in commodity derivatives is by financial firms rather than by users of commodities (Basu and Gavin, 2011), and thus it is more reasonable to assume that FIs invest in commodities rather than entrepreneurs. Under this framework, if FIs can own assets associated not only with capital but also with commodities, changes in CPs will affect the net worth of FIs. Thus, FIs' investment in the asset tied to capital will change, and in turn output will be affected. Without commodities as an asset, however, the channel through the net worth of FIs would not exist.

Specifically, suppose that firms produce goods by using commodities, capital and labour as inputs and that FIs own two assets tied to capital and commodities. Then, the net worth of FIs is affected by prices of capital and commodities. Under this environment, if CPs decrease, the net worth of FIs will fall, *ceteris paribus*. This will lead to a decrease in FIs' demand for investment, which will partly offset the impact of the reduced marginal costs of firms due to the fall in CPs. Therefore, the positive effects of the fall in CPs on the economy will be reduced.

However, it is impossible to capture the linkage between CPs and the net worth of FIs with the existing models with financial frictions despite its importance, since in these models the role of commodities as an asset class is omitted. For example, BGG assume that entrepreneurs borrow money from FIs to purchase capital and are leveraged. In that model, due to the existence of the counter-cyclical external finance premium, when an adverse productivity shock hits the economy, the price of capital falls more initially, which amplifies and propagates the shock to the economy compared to the frictionless models (the financial accelerator). Considering that in BGG the FIs borrow from investors without frictions, Hirakata, Sudo and Ueda (2009) suppose that both entrepreneurs and FIs are leveraged, and thus there are chained credit contracts (between investors and FIs, and FIs and entrepreneurs). They show that under the chained credit contracts the financial accelerator is strengthened, because the two contracts work complementarily. The model of Luk and Vines (2013), henceforth LV, is based on Hirakata, Sudo and Ueda (2009). They assume that FIs buy shares in capital issued by entrepreneurs, rather than assuming like Hirakata, Sudo and Ueda (2009) that FIs lend money to entrepreneurs. They assume that there is symmetric information between FIs and entrepreneurs, and thus no monitoring cost arises (such that they split the profits according to the shares of their investments), while information is asymmetric between FIs and investors. They find that under their assumptions the economy is more volatile than it is in the model of Hirakata, Sudo and Ueda (2009).[3] In addition to these models, there are also models with financial frictions and the CSV approach that contain two assets for FIs or entrepreneurs. They extend either BGG or Hirakata and Sudo and Ueda (2009) to two-country models. Therefore, the two assets are capital in home and foreign countries (see Ueda, 2012; and Dedola and Lombardo, 2012). In any case, existing models consider FIs or entrepreneurs holding only assets tied to capital.

In this chapter, I set out a model with financial frictions, the CSV approach and FIs investing in assets tied to both commodities and capital in a RBC model with adjustment costs in capital formation by extending the model of BGG. I use this model to show that if FIs can hold two assets tied to commodities as well as capital of firms, the effects of an adverse CP shock on the economy will be attenuated. In the model, commodities are included in consumption and the production function for noncommodity goods, and CPs are determined exogenously. I simulate the responses of the macroeconomic variables to a negative CP shock under varying proportions of commodity investment in FIs' capital investment, and compare them to those of a model that omits FIs' investment in commodities to see whether commodities as an asset class play a role in the reduced impacts of CP shocks.

The chapter is organised as follows. Section 2 shows the empirical relationship between CPs and net worth of FIs. Section 3 describes the model with financial frictions, the CSV

[3] This is because in Hirakata, Sudo and Ueda (2009) a negative shock forces FIs to set a lower threshold value of the idiosyncratic shocks to entrepreneurs. Thus, a fall in the threshold value to entrepreneurs dampens the amplication of the shock. However, in LV the contract between FIs and entrepreneurs is frictionless, and thus the contract does not involve idiosyncratic shocks to entrepreneurs. Therefore, the dampening effect due to a fall in the threshold value to entrepreneurs is absent, which brings about a larger amplification than Hirakata, Sudo and Ueda (2009).

approach and FIs investing in two assets tied to both capital and commodities. Section 4 explains how the existence of commodities as an asset class differs from BGG and why it is important. Section 5 provides the model calibration, and gives the results of the experiments. Section 6 concludes.

2. Commodity prices and net worth of FIs

Figure 2 shows that the value of commodity derivative contracts of FIs with derivatives in the U.S. massively increased in the mid 2000s. To be specific, the ratio of the value of commodity derivative contracts to total assets was about 5% in the late 1990s and early 2000s. Since the mid 2000s, it has been stable and has fluctuated around 10%. This clearly shows that the portions of commodity derivatives in FIs' portfolios have become greater since the mid 2000s compared to the past, and thus the importance of CPs to FIs has been bigger as well.

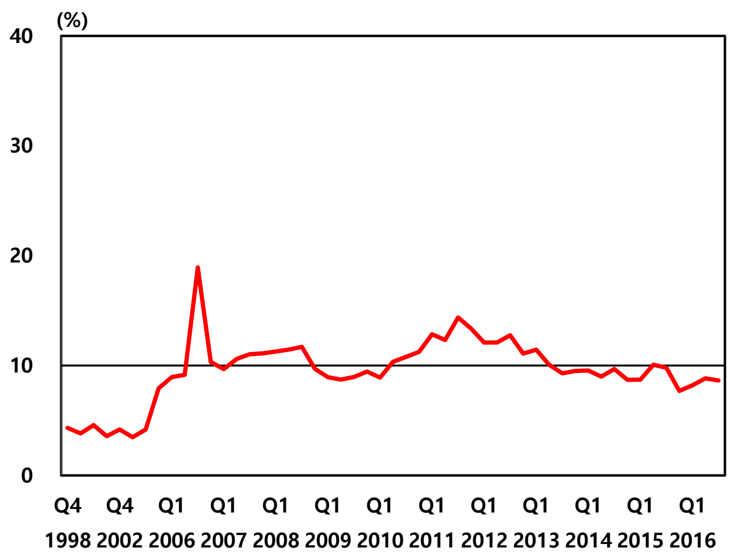


Figure 2: Ratio of commodity derivatives to total asset

Note: The ratio is notional amount of total commodity derivative contracts divided by total asset for commercial banks, saving associations and trust companies with derivatives in the U.S.
Source: Quarterly Report on Bank Trading and Derivatives Activities, Office of the Comptroller of the Currency, U.S. Department of the Treasury

As FIs' holdings of commodity derivatives have increased, the weight of trading revenues from commodity derivatives in the total trading revenue of FIs with derivatives has risen as well. Between 1998 and 2004 the average quarterly trading revenues of commodity derivatives was less than 100 million dollars, but during Q1 2005-Q3 2016 it increased to about 300 million dollars (see Figure 3). Because trading revenues from derivatives are a part of the total equity capital of FIs, the effects of commodity derivatives on the net worth of FIs have become larger since the mid 2000s, and thus CPs have affected the net worth of FIs by more than they did before the mid 2000s.

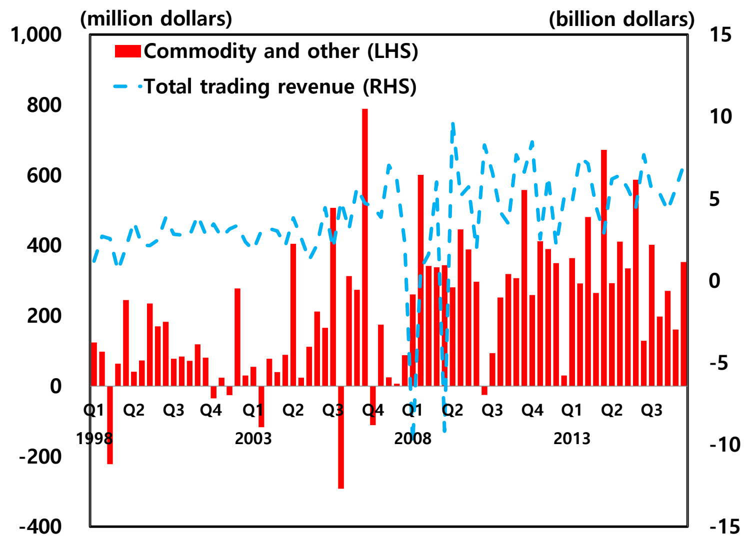


Figure 3: Trading revenue of derivatives

Note: Trading revenues for commercial banks, saving associations and trust companies with derivatives.
Source: Quarterly Report on Bank Trading and Derivatives Activities, Office of the Comptroller of the Currency, U.S. Department of the Treasury

In order to find a more precise relationship between CPs and the net worth of FIs, I simply regress the total equity capital for commercial banks in the U.S. (net worth of FIs) on CPs and other control variables following Paul and Mallik (2003). Moreover, to know whether CPs have become more significant in explaining total equity capital, two sample periods are used: Q2 1995-Q3 2016 and Q1 2005-Q3 2016. Specifically, the following simple regression model is estimated.

$$\varDelta \ln N_t = \alpha_0 + \alpha_1 \varDelta \ln N_{t-1} + \alpha_2 \varDelta \ln IP_t + \alpha_3 \varDelta \ln CPI_t$$

$$+\alpha_4 \varDelta INT_t + \alpha_5 \varDelta \ln SP_t + \alpha_6 \varDelta \ln CP_t + \varepsilon_t$$

where N is the log total equity capital for commercial banks in the U.S., IP is the log U.S. industrial production index, CPI is the log U.S. consumer price index, INT is the U.S.

3-month treasury bill rate, SP is the log S&P 500 index, and CP is the log commodity price index.[4]

Table 1: Estimation results

	Q2 1995-Q3 2016	Q1 2005-Q3 2016
Constant	0.0172*** (0.0032)	0.0189*** (0.0042)
Lagged dependant variable	0.2477*** (0.0815)	0.0542 (0.1102)
Industrial production	-0.1231 (0.1421)	-0.1657 (0.1779)
CPI inflation	-0.2059 (0.4128)	-0.6676 (0.4203)
Interest rate	0.0091 (0.0057)	0.0092 (0.0086)
S&P 500	-0.0325 (0.0262)	-0.0482 (0.0297)
Commodity prices	0.0216 (0.0266)	0.0644** (0.0311)

Notes: Values within parentheses are HAC standard errors. ** and *** denote significant at 5% and 1% respectively

According to the estimation results in Table 1, the coefficient of CPs for the period Q2 1995-Q3 2016 is not significant, while that for the period Q1 2005-Q3 2016 is significant at 5% level. This shows well that CPs significantly affect the net worth of FIs after 2005, and thus the relationship between CPs and the net worth of FIs is statistically significant in the period.

[4] Paul and Mallik (2003) use the growth rate of the bank and finance stock price index (stock prices are frequently used as proxies for net worths) as the dependent variables, and lagged dependent variable, GDP growth rate, CPI inflation, growth rate of 3-month bank bill rates and error correction term as independent variables to find determinants of the bank and finance stock price index in Australia. Differently from Paul and Mallik (2003), growth rate of CPs and S&P 500 index as explanatory variables are added. Moreover, according to the cointegration test there does not exist a long run equillibrium relationship, and thus the error correction term is excluded.

Source of N, IP, CPI and INT is the U.S. Federal Reserve Economic Data, that of CP is the IMF, and that of SP is the S&P Dow Jones Indices.

3. The Model[5]

The model is very close to that of BGG, which has a similar structure to LV.[6] The main differences between this model and BGG are that firms use commodities as well as labour and capital as an input to produce goods, that commodities are in the consumption basket of households, and that FIs invest not only in shares in capital issued by firms but also in commodities.

3.1. Financial market

The framework of the financial market in this model is closely related to that of Gertler and Karadi (2011). Specifically, firms issue shares to acquire funds which are necessary to purchase capital for production, and there is no friction in the process of firms obtaining funding from FIs. Only FIs face credit constraints in obtaining funds from investors.

The financial market consists of three types of agents: investors, firms and FIs. There are two kinds of contracts in the financial market: loan contracts between FIs and investors, and share contracts between firms and FIs.[7] FIs have their own net worth, N, which is not enough to invest in commodities and shares in capital issued by firms. Thus, FIs enter into loan contracts with investors to borrow money.

As in BGG, FIs face idiosyncratic shocks to their return, ω. Therefore, the ex post gross return to FI i's investment is equal to $\omega_i R^F_{t+1}$, where R^F_{t+1} is the ex post aggregate return to investments of FIs. $\ln \omega$ follow a normal distribution with mean $-\frac{1}{2}\sigma^2$ and variance σ^2. Under this assumption, $\mathbb{E}[\omega] = 1$. The CDF of ω is $F(\cdot)$ and the PDF is $f(\cdot)$. ω is $i.i.d.$ across time and across FIs. $\frac{\partial\{\omega h(\omega)\}}{\partial\omega} > 0$ is also imposed where $h(\omega) = \frac{f(\omega)}{1-F(\omega)}$ is the hazard rate. Furthermore, as in Christiano, Motto and Rostagno (2014), σ, called the risk, is time-varying

[5] See Appendix A for details of the model.

[6] The difference between BGG and LV is trivial. If both the net worth of entrepreneurs and the entrepreneurial share of labour are set to 0 in LV, then LV and BGG are the same, i.e. the LV model becomes a special case of the BGG model.

[7] Since there are no frinctions in share contracts between FIs and firms, the contracts are not described.

and follows an AR(1) process.[8]

$$\ln \sigma_t = \Lambda + \rho_\sigma \ln \sigma_{t-1} + u_t \tag{1}$$

where $\Lambda = (1 - \rho_\sigma) \ln \sigma$ and σ is the steady state value of σ_t. u_t is the risk shock.

3.1.1. Loan contract between financial intermediaries and investors

As in BGG, CSV is assumed. Since the return on FIs' investment is subject to the idiosyncratic shock, ω, if investors wish to observe the shock for a specific FI, they have to pay a monitoring cost. The monitoring cost is a fixed fraction, μ, of the entire wealth of the FI.

In each period, FI i wishes to invest $Q_t K_{i,t+1}$ in shares in capital issued by firms and $p_t x_{i,t}^F$ in commodities (i.e. commodity derivatives), where x^F is units of commodity composite used noncommercially and p is the price of a unit of commodity composite.[9] Therefore, FI i needs to borrow $Q_t K_{i,t+1} + p_t x_{i,t}^F - N_{i,t+1}$ from investors.[10] Accordingly, FIs' balance sheet is given in Figure 4.

· **Asset**	· **Liability**
- Share: QK	- Borrowing: $QK + px^F - N$
- Commodity: px^F	· **Equity**
	- Net worth: N

Figure 4: FI's balance sheet

FI i has to repay the principal and interest, $Z_{i,t+1} \left(Q_t K_{i,t+1} + p_t x_{i,t}^F - N_{i,t+1} \right)$, to investors, where $Z_{i,t+1}$ is the gross non-default loan rate, if it does not default. If it defaults, investors that lend money to FI i pay the monitoring cost and take the whole wealth of the FI i.

It is further assumed that FIs invest a fixed portion, $\tau \in [0, 1]$, of their expenditure on

[8] In Christiano, Motto and Rostagno (2014) $u_t = \varsigma_{0,t} + \varsigma_{1,t-1} + \cdots + \varsigma_{p,t-p}$. $\varsigma_{j,t-j}$, $j = 0, 1, \cdots, p$, is *i.i.d.* mean zero random variable and orthogonal to σ_{t-j}, $j \geq 1$. In period t, $\varsigma_{j,t}$, $j = 0, 1, \cdots, p$, is known. $\varsigma_{0,t}$ is the unanticipated component of u_t, and $\varsigma_{j,t}$ is the anticipated, or news, components of u_{t+j} for $j > 0$. However, the anticipated components are omitted in this model.

[9] In period t, FIs buy x_t^F units of commodity composite at p_t and sell them at p_{t+1} in period $t+1$. Since this is a financial transaction, this does not involve trading real commodities like futures option trades.

[10] $N_t = \sum_i N_{i,t}$ and $K_t = \sum_i K_{i,t}$ where $i \in \{1, 2, \cdots, \infty\}$.

investment in shares in capital issued by firms, $Q_t K_{i,t+1}$, in commodities in each period, which implies[11]

$$p_t x^F_{i,t} = \tau Q_t K_{i,t+1} \tag{2}$$

Thus, the ex post aggregate return to investments of FIs is

$$R^F_{t+1} = \frac{1}{1+\tau}(R^K_{t+1} + \tau R^x_{t+1}) \tag{3}$$

where R^K_{t+1} is the ex post aggregate return to FIs' investment in shares in capital which is the same as the gross return averaged across firms, and R^x_{t+1} is the return to FI's investment in commodities.

$$R^x_{t+1} = p_{t+1}/p_t + \Delta \tag{4}$$

where $\Delta > 0$ makes the steady state return to commodity investment, R^x, equal to the steady state return to investment in shares in capital, R^K. This can be thought of as the saved transaction costs due to the absence of real commodity trading costs such as transportation and storage costs, or simply risk spread.

Since this is the standard debt contract, there exists a threshold value of the idiosyncratic shocks, $\bar{\omega}_i$, for FI i (see Townsend, 1979). If $\omega_i \geq \bar{\omega}_i$, FI i makes enough profit to pay back investors, while if $\omega_i < \bar{\omega}_i$, it defaults. Then, $\bar{\omega}_{i,t+1}$ is such that

$$\bar{\omega}_{i,t+1} R^F_{t+1}(Q_t K_{i,t+1} + p_t x^F_{i,t}) = Z_{i,t+1}(Q_t K_{i,t+1} + p_t x^F_{i,t} - N_{i,t+1}) \tag{5}$$

Thus, $Z_{i,t+1}$ is increasing in $\bar{\omega}_{i,t+1}$.

Denote $\Gamma(\bar{\omega}_i) \in (0,1)$ the share of the returns on FI i's investment that goes to investors. Then, $\Gamma(\bar{\omega}_i) R^F(QK_i + px^F_i) = G(\bar{\omega}_i) R^F(QK_i + px^F_i) + (1 - F(\bar{\omega}_i)) Z_i (QK_i + px^F_i - N_i)$ holds, where $G(\bar{\omega}_i) = \int_0^{\bar{\omega}_i} \omega f(\omega) d\omega$. Using equation (5), this becomes $\Gamma(\bar{\omega}_i) = G(\bar{\omega}_i) + (1 - F(\bar{\omega}_i))\bar{\omega}_i$. Finally, considering the monitoring cost, the net share of the returns to FI i going to investors

[11] This relaxes the assumption in BGG that FIs invest all available funds in shares in capital issued by firms. Hence, if $\tau = 0$, this model is the same as BGG with commodities in the consumption and production function.

is

$$\Psi(\bar{\omega}_i) = \Gamma(\bar{\omega}_i) - \mu G(\bar{\omega}_i) \tag{6}$$

Unless the expected profit of the contract is higher than the risk free rate, R, investors do not participate in the contract. Therefore, the expected participation constraint is

$$\mathbb{E}_t[\Psi(\bar{\omega}_{i,t+1})R^F_{t+1}(Q_tK_{i,t+1} + p_t x^F_{i,t})] = R_{t+1}(Q_tK_{i,t+1} + p_t x^F_{i,t} - N_{i,t+1}) \tag{7}$$

where $\mathbb{E}_t$ is the expectations operation conditional on the information in t.

Risk averse FIs[12] choose the expenditure on investment, $Q_tK_{i,t+1}+p_t x^F_{i,t}$, and the threshold values of the idiosyncratic shocks, $\bar{\omega}_{i,t+1}$, to maximise their expected logarithm of profits, $\mathbb{E}_t\left[\ln[(1-\Gamma(\bar{\omega}_{i,t+1}))R^F_{t+1}(Q_tK_{i,t+1} + p_t x^F_{i,t})]\right]$. The first order condition is

$$\frac{\mathbb{E}_t[R^F_{t+1}]}{R_{t+1}} = \mathbb{E}_t\left[\frac{\Gamma_\omega(\bar{\omega}_{i,t+1})}{(1-\Gamma(\bar{\omega}_{i,t+1}))\Psi_\omega(\bar{\omega}_{i,t+1}) + \Gamma_\omega(\bar{\omega}_{i,t+1})\Psi(\bar{\omega}_{i,t+1})}\right] \tag{8}$$

where $\Gamma_\omega(\cdot) = \frac{\partial \Gamma(\cdot)}{\partial \omega}$, $\Psi_\omega(\cdot) = \frac{\partial \Psi(\cdot)}{\partial \omega}$, and $\frac{\mathbb{E}_t[R^F_{t+1}]}{R_{t+1}}$ is called the external finance premium.

The expected participation constraint, equation (7), and the first order condition, equation (8), fully describe the loan contract between investors and FIs. They determine the threshold value, $\bar{\omega}_{i,t+1}$, and the FI i's total investment, $Q_tK_{i,t+1} + p_t x^F_{i,t}$. Using equation (2), the expenditure on shares in capital, $Q_tK_{i,t+1}$, and the expenditure on commodities, $p_t x^F_{i,t}$, are determined as well.

3.1.2. Aggregation of the loan contract

Since the left-hand side of equation (8) is determined macroeconomically, every FI's choice for $\mathbb{E}_t[\bar{\omega}_{i,t+1}]$ is the same. Thus, equation (8) can be aggregated.

$$\frac{\mathbb{E}_t[R^F_{t+1}]}{R_{t+1}} = \mathbb{E}_t\left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right] \tag{9}$$

[12] There are various assumptions about the degree of risk aversion of investors and FIs. For example, BGG assumes that investors and entrepreneurs or FIs are risk neutral, while in Gertler and Karadi (2011) bankers borrow money from risk averse households and maximise expected terminal wealth. However, the degree of risk aversion of FIs cannot make notable differences.

Aggregating expected participation constraints, equation (7), yields

$$\mathbb{E}_t[\Psi(\bar{\omega}_{t+1})R^F_{t+1}(Q_tK_{t+1} + p_tx^F_t)] = R_{t+1}(Q_tK_{t+1} + p_tx^F_t - N_{t+1}) \tag{10}$$

Using equations (9) and (10), the relationship between FIs' leverage, $(Q_tK_{t+1} + p_tx^F_t)/N_{t+1}$, and the external finance premium can be obtained.

$$\frac{Q_tK_{t+1} + p_tx^F_t}{N_{t+1}} = s\frac{\mathbb{E}_t[R^F_{t+1}]}{R_{t+1}} \tag{11}$$

Equation (11) is critical in models with financial frictions. It shows that FIs' leverage is proportional to the external finance premium.[13] Specifically, everything else equal, an increase in the external finance premium brings about a fall in the threshold value of the idiosyncratic shocks from equation (10). Hence, FIs can borrow more money for investment and are leveraged more heavily.

3.1.3. Dynamic behaviour of net worth

The aggregate net worth of FIs depends on their aggregate earnings from the above contracts and their labour incomes, since it is assumed that FIs inelastically supply one unit of labour to operating firms. Let V_t be the aggregate earnings of FIs from the above contract. Then, the aggregate net worth of FIs evolves

$$N_{t+1} = \gamma^F V_t + W_{F,t} \tag{12}$$

where $V_t = (1 - \Gamma(\bar{\omega}_t))R^F_t(Q_{t-1}K_t + p_{t-1}x^F_{t-1})$ and $W_{F,t}$ is the labour incomes of FIs. Let γ^F be the survival probability for FIs.[14] When FIs quit their business, they consume all of their net worth. Thus, the consumption of quitting FIs is

$$C^F_t = (1 - \gamma^F)V_t \tag{13}$$

[13] $s = \mathbb{E}_t\left[\frac{\{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})+\Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})\}^2}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})\Gamma_\omega(\bar{\omega}_{t+1})}\right] > 0$. Since $1-\Gamma(\bar{\omega}_{t+1}) > 0$, $\Psi_\omega(\bar{\omega}_{t+1}) > 0$, $\Gamma_\omega(\bar{\omega}_{t+1}) > 0$, and the numerator of s is positive, $s > 0$. See Appendix A for details.

[14] At the end of every period, $1 - \gamma^F$ of FIs quit their business.

3.2. Goods Market

The RBC framework with capital adjustment costs is adopted for the setup of the goods market as in LV. It is further assumed that households consume commodities and noncommodity goods, and that firms use commodities together with capital and labour as an input to produce noncommodity goods. Commodities are imported from the world commodity market at an exogenous world price, and as usual the world commodity market is not explicitly modelled as in Kim and Loungani (1992), Atkeson and Kehoe (1999), etc.

3.2.1. Household

A representative household chooses consumption, labour supply and real lending to maximise her utility. For simplicity, log utility function of consumption and separability between consumption and labour are assumed. The utility function is

$$U = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \frac{L_{C,t}^{1+\chi}}{1+\chi} \right) \tag{14}$$

where C_t is consumption, $L_{C,t}$ is labour supply by households, β is the discount factor, and χ is the inverse of Frisch elasticity of labour supply.

The budget constraint is

$$C_t + B_{t+1} = W_t L_{C,t} + R_t B_t + \Pi_t \tag{15}$$

where B_t is the real lending, W_t is the real wage, R_t is the real return from lending, and Π_t is profits remitted by firms.

The first order conditions of a representative household's utility maximisation problem are

$$1 = \beta \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} R_{t+1} \right] \tag{16}$$

$$W_t = C_t L_{C,t}^{\chi} \tag{17}$$

These are standard. The first equation is the Euler equation, and the second equation is the condition of intratemporal substitution between consumption and labour.

Since households consume both commodities and noncommodity goods, the aggregate consumption consists of noncommodity goods, $C_{n,t}$, and commodities, $C_{x,t}$. The households use the following constant elasticity of substitution (CES) aggregator function for the aggregate consumption borrowed from Bodenstein, Erceg and Guerrieri (2011), and the aggregate price, $\mathbb{P}_t$, has similar form.

$$C_t = \left\{(1-b)^{\frac{1}{\psi}} C_{n,t}^{\frac{\psi-1}{\psi}} + b^{\frac{1}{\psi}} C_{x,t}^{\frac{\psi-1}{\psi}}\right\}^{\frac{\psi}{\psi-1}} \tag{18}$$

$$\mathbb{P}_t = \left\{(1-b)P_{n,t}^{1-\psi} + bP_t^{1-\psi}\right\}^{\frac{1}{1-\psi}} \tag{19}$$

where $P_{n,t}$ and P_t is the nominal price of noncommodity goods and the nominal price of commodities, respectively. The parameters b and ψ determine the importance of commodities and the price elasticity of demand between two goods, respectively.[15] Thus, the household demands for noncommodity goods and commodities are

$$C_{n,t} = (1-b)C_t p_{n,t}^{-\psi} \tag{20}$$

$$C_{x,t} = bC_t p_t^{-\psi} \tag{21}$$

where $p_{n,t} = \frac{P_{n,t}}{\mathbb{P}_t}$ and $p_t = \frac{P_t}{\mathbb{P}_t}$ where lowercase letter p denotes real prices.[16]

3.2.2. Firms

A representative firm produces noncommodity goods using capital, labour and commodities. The production function is a nested CES with constant returns to scale following Kim and Loungani (1992) and Dhawan and Jeske (2008).

$$Y_t = A_t\{(1-a)K_t^{\frac{\nu-1}{\nu}} + ax_t^{\frac{\nu-1}{\nu}}\}^{\frac{\nu\alpha}{\nu-1}} L_t^{1-\alpha} \tag{22}$$

[15] Similarly, $C_t^F = \left\{(1-b)^{\frac{1}{\psi}} C_{n,t}^{F\frac{\psi-1}{\psi}} + b^{\frac{1}{\psi}} C_{x,t}^{F\frac{\psi-1}{\psi}}\right\}^{\frac{\psi}{\psi-1}}$.

[16] Similarly, $C_{n,t}^F = (1-b)C_t^F p_{n,t}^{-\psi}$ and $C_{x,t}^F = bC_t^F p_t^{-\psi}$. The real price of a noncommodity good is treated as a numeraire ($p_{n,t} = 1$).

where x is units of commodity composite used in production, and $1-\alpha$ is the labour share of income. a and ν determine the importance of commodities and the elasticity of substitution between capital and commodities. A is the aggregate productivity and follows an AR(1) process as usual.

$$\ln A_t = \kappa + \rho_A \ln A_{t-1} + \varepsilon_t \tag{23}$$

where ε is the aggregate productivity shock, $\kappa = (1-\rho_A)\ln A$, and A is the steady state value of A_t. As in BGG, L_t is a composite of the labour that is supplied by households ($L_{C,t}$) and FIs ($L_{F,t}$). L_t is expressed by

$$L_t = L_{C,t}^{1-\Omega_F} L_{F,t}^{\Omega_F} \tag{24}$$

Firms purchase capital at the end of period $t-1$ to produce noncommodity goods in period t, and sell the non-depreciated capital back to capital producers at the end of period t. Hence, the profit maximisation problem is

$$\max_{K_t, x_t, L_{C,t}, L_{F,t}} [Y_t + (1-\delta)Q_t K_t - R_t^K Q_{t-1} K_t - p_t x_t - W_t L_{C,t} - W_{F,t} L_{F,t}]$$

where δ is the depreciation rate. The corresponding first order conditions with respect to $L_{C,t}$ and $L_{F,t}$ are

$$W_t = (1-\alpha)(1-\Omega_F)\frac{Y_t}{L_{C,t}} \tag{25}$$

$$W_{F,t} = (1-\alpha)\Omega_F \frac{Y_t}{L_{F,t}} \tag{26}$$

The realised return on capital is obtained by the first order condition with respect to K_t.

$$R_t^K = \frac{1}{Q_{t-1}}\left\{(1-\delta)Q_t + \alpha(1-a)K_t^{-\frac{1}{\nu}} \frac{Y_t}{(1-a)K_t^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}}\right\} \tag{27}$$

The first order condition with respect to x_t is

$$p_t = a\alpha x_t^{-\frac{1}{\nu}} \frac{Y_t}{(1-a)K_t^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}} \tag{28}$$

CPs are determined exogenously in the world commodity market and follows AR(1) as in Wei (2003) and Castillo, Montoro and Tuesta (2007).[17]

$$\ln p_t = \rho \ln p_{t-1} + \eta_t \tag{29}$$

where η is the CP shocks. Therefore, the return to FIs' investment in commodities, R^x, can be expressed by the CP shocks and past values of CPs.

$$R_t^x = \exp\left[\rho \ln \frac{p_{t-1}}{p_{t-2}} + \eta_t - \eta_{t-1}\right] + \varDelta \tag{30}$$

3.2.3. Capital goods producers

The capital goods producers own the technology that converts final goods to capital goods. In each period, they buy I_t of noncommodity goods and $(1-\delta)K_t$ of used capital from firms. They then produce new capital goods, K_{t+1}. Thus, the capital goods producer's problem is the following

$$\max_{K_{t+1}} Q_t K_{t+1} - (1-\delta)Q_t K_t - I_t$$

subject to the law of motion for capital

$$K_{t+1} = (1-\delta)K_t + I_t - \frac{\xi}{2}\frac{(K_{t+1}-K_t)^2}{K_t} \tag{31}$$

[17] This is different from Kim and Loungani (1992), Atkeson and Kehoe (1999) and Dhawan and Jeske (2008) in which energy prices follow ARMA(1,1). This difference does not affect the simulation results of the model.

where I is investment and ξ is the parameter associated with adjustment costs. The first order condition gives the price of capital.

$$Q_t = 1 - \xi + \xi \frac{K_{t+1}}{K_t} \tag{32}$$

3.2.4. Resource constraint

In each period, all produced noncommodity goods are used for either noncommodity consumption, commodity consumption, investment, purchase of commodities for firms' production or monitoring cost. Thus, the resource constraint is given by

$$Y_t = (C_{n,t} + C^F_{n,t}) + p_t(C_{x,t} + C^F_{x,t}) + I_t + p_t x_t + \mu G(\bar{\omega}_t) R^F_t (Q_{t-1} K_t + p_t x^F_t) \tag{33}$$

The last term is the monitoring cost of investors.[18]

4. Commodities as an asset class

Main differences of this model from BGG originate from the existence of commodities as an asset class in the financial market. Other features are trivially different from or the same as BGG. In this section, how commodities as an asset class cause changes to the model compared to BGG and why they are important and relevant are explained.

4.1. How commodities as an asset class cause changes to the model

The existence of commodities as an asset class means that FIs' aggregate return to investment, R^F, as well as their net worth, N, are differently affected by CP shocks compared to BGG.

First of all, for simplicity, suppose that FIs' return to investment in shares issued by firms, R^K, does not change according to changes in CPs. In BGG with FIs[19] holding assets only

[18] Note that according to BGG, C^F_t and the monitoring cost have relatively low weights under any reasonable parameterisation of the model, and thus have no recognisable effect on dynamics.

[19] FIs in this model and entrepreneurs in BGG have the identical role. The term 'FIs' therefore is used to refer to entrepreneurs in BGG.

associated with capital, R^F is unaffected by changes in CPs, since $\tau = 0$ in equation (3), and thus $px^F = 0$ in equation (2). Because R^F does not change and $px^F = 0$, from equation (10), $\bar{\omega}$ does not change either, which means that N is unaffected via equation (12). In this model, however, $\tau \in [0, 1]$ and $px^F > 0$. Therefore, R^F is increasing in CPs. Specifically, if CPs fall, by equations (3) and (4), R^F will decrease due to a fall in R^x. Then, from equation (10), $\Psi(\bar{\omega})$ will rise. Since $\Psi_\omega > 0$, $\bar{\omega}$ will go up. A rise in $\bar{\omega}$ will lead to a decrease in $1 - \Gamma(\bar{\omega})$, because $\Gamma_\omega > 0$. Finally, by equation (12), N will fall.

Now, consider the more general case in which changes in CPs affect both R^x and R^K. Because from equation (28), x is decreasing in p, a fall in CPs will lead to a rise in the commodity demand in production, which will cause an increase in R^K since R^K is increasing in x from equation (27). R^x will go down via equation (4). In BGG in which $\tau = 0$, R^F depends only on R^K, whereas in this model in which $\tau \in [0, 1]$, R^F is affected by both R^K and R^x. Consequently, R^F in this model will rise by less compared to BGG. Thus, N will increase by less compared to BGG.

To summarise, due to the existence of commodities as an asset class in the financial market in this model, the net worth and aggregate return to investment of FIs are affected less by CP shocks than those in BGG in which there is no commodities as an asset class.

4.2. Importance and relevance of commodities as an asset class

The importance and relevance of commodities as an asset class in this model result from the fact that by investing in commodities FIs can hedge against the risk of their investment in shares in capital issued by firms.

To be specific, the demand for commodities in production, x, is decreasing in CPs, and the aggregate return to capital, R^K, is increasing in the demand for commodities. Hence, R^K is decreasing in CPs. However, the aggregate return on commodity investment, R^x, is increasing in CPs. Therefore, R^K and R^x react in the opposite directions to changes in CPs, which enables FIs to hedge against the risk of investment in shares in capital issued by firms to CP shocks by investing in commodities. For instance, a rise in CPs will lead to an increase in R^x by equation (4), but a fall in R^K by equations (27) and (28). If FIs do not invest in commodities as in BGG, R^F will fall. In this model, however, since FIs hold commodities as an asset, R^F declines by less due to a rise in R^x, i.e. when FIs invest in commodities, their return to investment fluctuates by less in response to CP shocks.

Furthermore, investment in commodities makes FIs' return to investment less volatile not only to CP shocks but also to other shocks such as aggregate productivity shocks and risk shocks, so long as the return on commodities fluctuates by less in response to the shocks than the return on shares in capital issued by firms. Specifically, suppose that an adverse shock such as a negative aggregate productivity shock and a positive risk shock hits the economy. And assume that the shock leads to a moderate fall in CPs. Then, although the demand for commodities in production will rise due to the fall in CPs, the demand for capital will decline, which will cause a fall in the return on capital. Since CPs decrease moderately, the return on commodities will decrease less than the return on capital. Hence, if FIs invest in commodities, their return on investment will fall by less compared to the case in which they do not hold commodities as an asset.

Now, suppose that an adverse shock and a positive CP shock hit the economy at the same time. Then, CPs will rise, and thus the return on commodity investment will go up as well. However, the return on capital will decline due to a fall in the demand for capital in production following both shocks. Therefore, when FIs hold commodities as an asset, their return on investment will decline by less compared to when they do not hold commodities.

The existence of commodities as an asset class in this model is very consistent with the fact that FIs use commodity derivatives to hedge against equity risk. In BGG FIs' return to investment depends solely on the aggregate return to capital and there are no instruments for FIs to diversify the risk of investment in shares in capital, while FIs in this model have such instruments. Therefore, this model is more relevant than BGG in considering the existence of commodities as a hedging instrument for FIs.

5. Model analysis

5.1. Calibration

The parameter and steady state values mainly follow BGG, LV, Kim and Loungani (1992) and Dhawan and Jeske (2008). The calibration is based on quarterly U.S. data.

Furthermore, I consider three cases for calibration: $\tau = 0$ (BGG with commodities in the consumption and production function), $\tau = 0.03$ and $\tau = 0.05$. By considering three cases for the parameter value for τ, I can show how the responses of the macroeconomic variables to an adverse CP shock change as FIs invest in commodities to different degrees.

First of all, since β is 0.99 (same as BGG and LV), $R = \beta^{-1} = 1.0101$.[20] The steady state risk spread, $R^K - R$, is set to 0.005 (same as BGG and LV), and thus $R^K = 1.0151$. Because $p = 1$ and $R^x = R^K$, $\mathit{\Delta} = 0.0151$ and $R^F = 1.0151$.

I assume that the steady state ratio of capital to net worth, $\frac{K}{N}$, is 4 (same as Gertler and Karadi, 2011), and thus the steady state ratio of commodity investment to net worth, $\frac{x^F}{N}$, is equal to 4τ by equation (2).

Following Natal (2012), the elasticity of substitution between commodities and noncommodity goods in the aggregate consumption are assumed to be $\psi = 0.3$.[21] The weight of commodities in the aggregate consumption, b, is 0.11 which is consistent with the NIPA data, the average ratio of commodity consumption[22] to total consumption for Q1 1992-Q4 2015. The labour share of income, $1 - \alpha$, is equal to 0.64, and ν is assumed to be 1 (same as Kim and Loungani, 1992). I assume that the inverse of Frisch elasticity of labour supply, χ, is assumed to be 3 following Ueda (2012). The depreciation rate, δ, is 0.025, Ω_F is set to 0.01, and ξ is equal to 10 as in LV.

The steady state capital/commodity, K/x, is assumed to be 146.39.[23] Now, we can

[20] The variables without time subscript, t, refer to their steady state values.
[21] This implies that commodities and noncommodity goods are complements.
[22] Gasoline and other energy goods, plus food and beverages purchased for off-premises consumption
[23] I follow Dhawan and Jeske (2008) rather than Kim and Loungani (1992), because the calibration of the former is based on U.S. quarterly data and that of the latter use U.S. annual data. Dhawan and Jeske (2008) assume that capital/energy is 232. However, in this model, firms use all commodities, rather than only energy as in Dhawan and Jeske (2008). Considering that the weight of energy in the IMF's commodity price index is 0.631, 232×0.631=146.39 as the steady state capital/commodity is appropriate.

compute the steady state investment/output, I/Y, and a by using equations (27), (28) and (31) in steady state. a is set to 0.1449. I/Y is 0.19 which matches the average ratio of gross private domestic investment to GDP for 1990-2015 from the NIPA data (0.16). By using I/Y, K/N and x^F/N, $N/Y = 1.92$ and $x^F/Y = 4\tau N/Y$. From I/Y and K/x, $x/Y = 0.05$. Using resource constraint, the steady state consumption/output, C/Y, is 0.76 which is very close to the value in the standard RBC literature (0.75).

Table 2: Parameter values

β	Δ	χ	δ	Ω_F	ξ	α	b
0.99	0.0151	3	0.025	0.01	10	0.36	0.11
ψ	ν	a	ρ	ρ_A	ρ_σ	μ	γ^F
0.3	1	0.1449	0.97	0.95	0.97	0.0467 (0.0465) [0.0463]	0.9701 (0.9696) [0.9693]

Note: Numbers without bracket means $\tau = 0$ (BGG with commodities in the consumption and production function), and numbers in ( ) and [ ] mean $\tau = 0.03$ and $\tau = 0.05$, respectively.

Table 3: Steady state values

R	R^x	R^F	R^K	$\frac{K}{N}$	x^F/N	x/Y
1.0101	1.0151	1.0151	1.0151	4	4τ	0.05
N/Y	I/Y	C/Y	$F(\bar{\omega})$	$\bar{\omega}$	σ	Z
1.92	0.19	0.76	0.02	0.7477 (0.7549) [0.7595]	0.1370 (0.1326) [0.1298]	1.0120 (1.0119) [1.0119]

Note: Numbers without bracket means $\tau = 0$ (BGG with commodities in the consumption and production function), and numbers in ( ) and [ ] mean $\tau = 0.03$ and $\tau = 0.05$, respectively.

The failure rate of financial intermediaries, $F(\bar{\omega})$, is 2% (same as Hirakata, Sudo and Ueda, 2009; and LV). Using the definition of log-normal distribution, the steady state expected participation constraint and first order condition of FI's problem, the steady state threshold value of the idiosyncratic shocks ($\bar{\omega}$) and variance of $\ln \omega$ (σ) can be obtained. Therefore, the monitoring cost (μ), the survival probability for FIs (γ^F), $G(\bar{\omega})$, the steady state share of FI's return going to investors ($\Gamma(\bar{\omega})$), $\Psi(\bar{\omega})$ and derivatives of $F(\bar{\omega})$, $G(\bar{\omega})$, $\Gamma(\bar{\omega})$ and $\Psi(\bar{\omega})$ can be computed, and using equation (5) in steady state, the steady state loan rate (Z) can be calculated.

$\rho_A = 0.95$ as in Dhawan and Jeske (2008), and ρ_σ is set to 0.97 as in Christiano, Motto and Rostagno (2014). Finally, $\rho = 0.97$ is estimated using Bayesian techniques.[24]

Tables 2 and 3 list steady state and parameter values.[25]

5.2. Experiments

The first experiment aims to show how the model responds to a negative 1% deviation shock to CPs. By conducting this experiment, how commodities as an asset class can dampen the effects of CP shocks on the economy can be shown. Then I analyse the responses of the model to a 1% positive deviation shock to productivity and a 10% deviation shock to risk.

5.2.1. A negative CP shock

In this section, the responses of the model to a negative CP shock are analysed to see whether the presence of commodities as an asset class in the model can dampen the effects of the shock. Figure 5 presents the responses of the model to a negative CP shock according to values of τ.

First, consider the case of $\tau = 0$ (i.e. BGG with commodities in the consumption and production function). In response to a negative CP shock, firms' demand for commodities, x, rises from equation (28), which leads to an increase in the marginal productivity of capital (the second term in the right hand side of equation (27)). Accordingly, firms' demand for capital increases. Thus, the price of capital, Q, jumps up, and then decreases along its

[24] Demeaned commodity price index (IMF) divided by GDP deflator (FRED) for the period Q1 1992 to Q3 2016 is used as demeaned real commodity prices. A Beta distritubtion, 0.96 and 0.05 are used as prior distribution, mean and standard deviation, respectively, and posterior mean and 90% confidence interval are 0.9722 and [0.9470, 0.999], respectively.

[25] When computing the steady state and parameter values, FIs' consumption and the monitoring cost in the resource constraint are omitted to obtain the same values for I/Y, x/Y and C/Y regardless of values of τ.

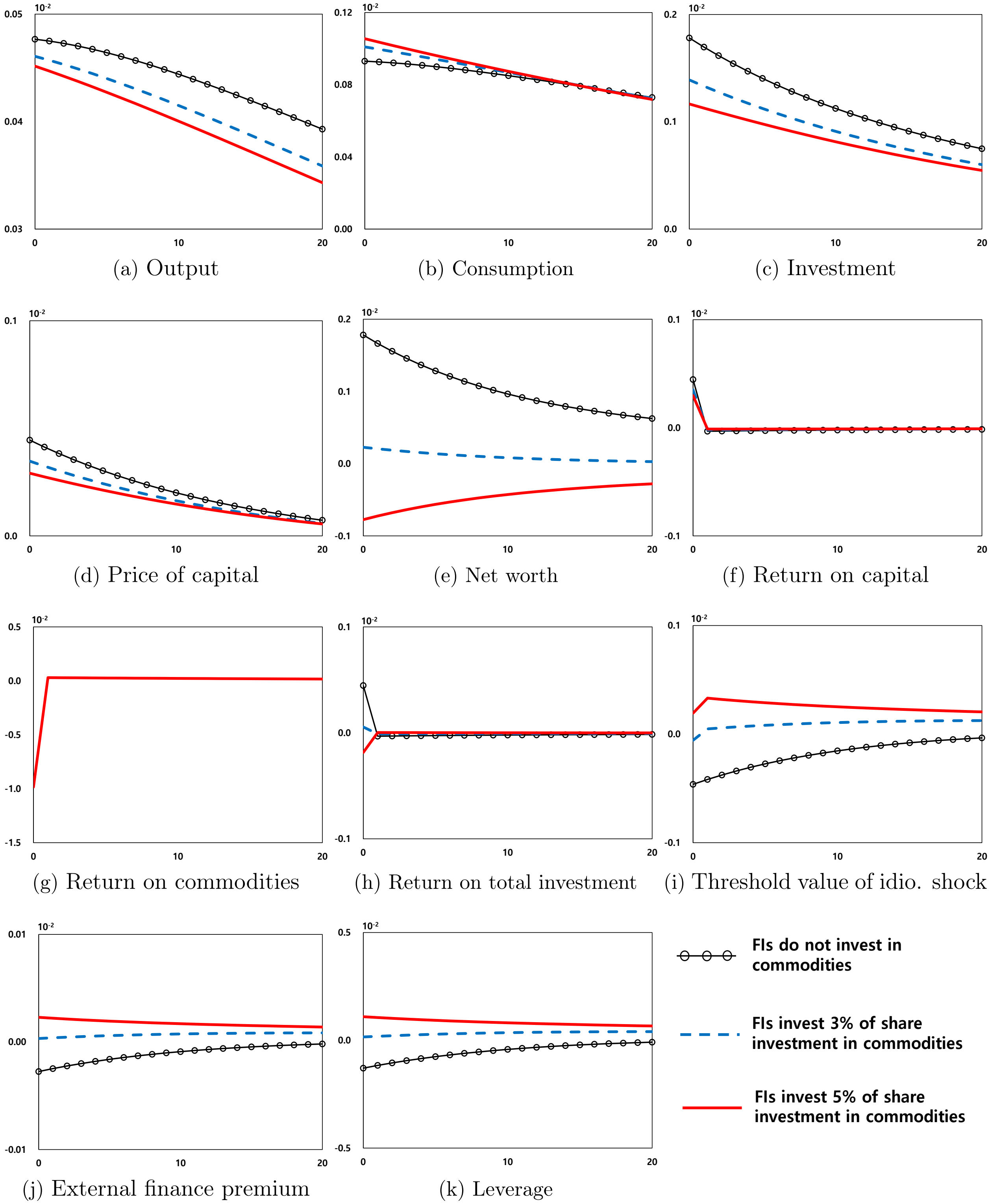
adjustment path. Since $R^K = R^F$[26] depends on Q, it rises initially, and then decreases. Due to the realised participation constraint, a rise in R^F brings about a fall in the threshold value of the idiosyncratic shocks, $\bar{\omega}$. Because R^F and the share of profit going to FIs in the loan contract, $1-\Gamma(\bar{\omega})$, increase ($\mathit{\Gamma}_\omega > 0$), the net worth of FIs, N, rises. Therefore, owing to the increased N and marginal productivity of capital, the investment goes up, and thus output increases.

However, if $\tau \in \{0.03, 0.05\}$, due to a fall in R^x, R^F rises by less or decreases despite a rise in R^K[27] thanks to a rise in the marginal productivity of capital. The smaller rise or fall in R^F brings about a smaller decrease or an increase in $\bar{\omega}$. Thus, $1-\Gamma(\bar{\omega})$ rises by less or goes down. Since R^F and $1-\Gamma(\bar{\omega})$ increase by less or decrease, N rises by less or falls. Therefore, FIs' investment in shares in capital issued by firms goes up by less. Although the marginal productivity of capital increases due to a fall in CPs, owing to the smaller increase or decrease in N, investment rises by less than it does when $\tau = 0$, and thus output increases by less. In other words, the more assets tied to commodities FIs hold, the less N increases, and thus the less investment and output rise.

To summarise, if FIs own assets tied to commodities, investment and output will increase by less following a negative CP shock. This is mainly because a fall in CPs causes not only an increase in the returns to FIs' investment in assets tied to capital but also a fall in the returns to FIs' investment in commodities. As a result, FIs' net worth falls or rises by less compared to the model with FIs holding assets only associated with capital. Thus, considering that trading in commodity derivatives has increased sharply since the 2000s, and that according to the literature such as Blanchard and Galí (2007), the impacts of CP shocks have decreased since the 2000s, the results of this experiment are consistent with the hypothesis that commodities as an asset class have played an important role in the recently reduced impacts of CP shocks on the economy.

[26] If $\tau = 0$, $R_t^F = R_t^K$.

[27] If $\tau \neq 0$, $R_t^F = \frac{1}{1+\tau}(R_t^K + \tau R_t^x)$.



(a) Output (b) Consumption (c) Investment

(d) Price of capital (e) Net worth (f) Return on capital

(g) Return on commodities (h) Return on total investment (i) Threshold value of idio. shock

(j) External finance premium (k) Leverage

Figure 5: Responses to a negative commodity price shock

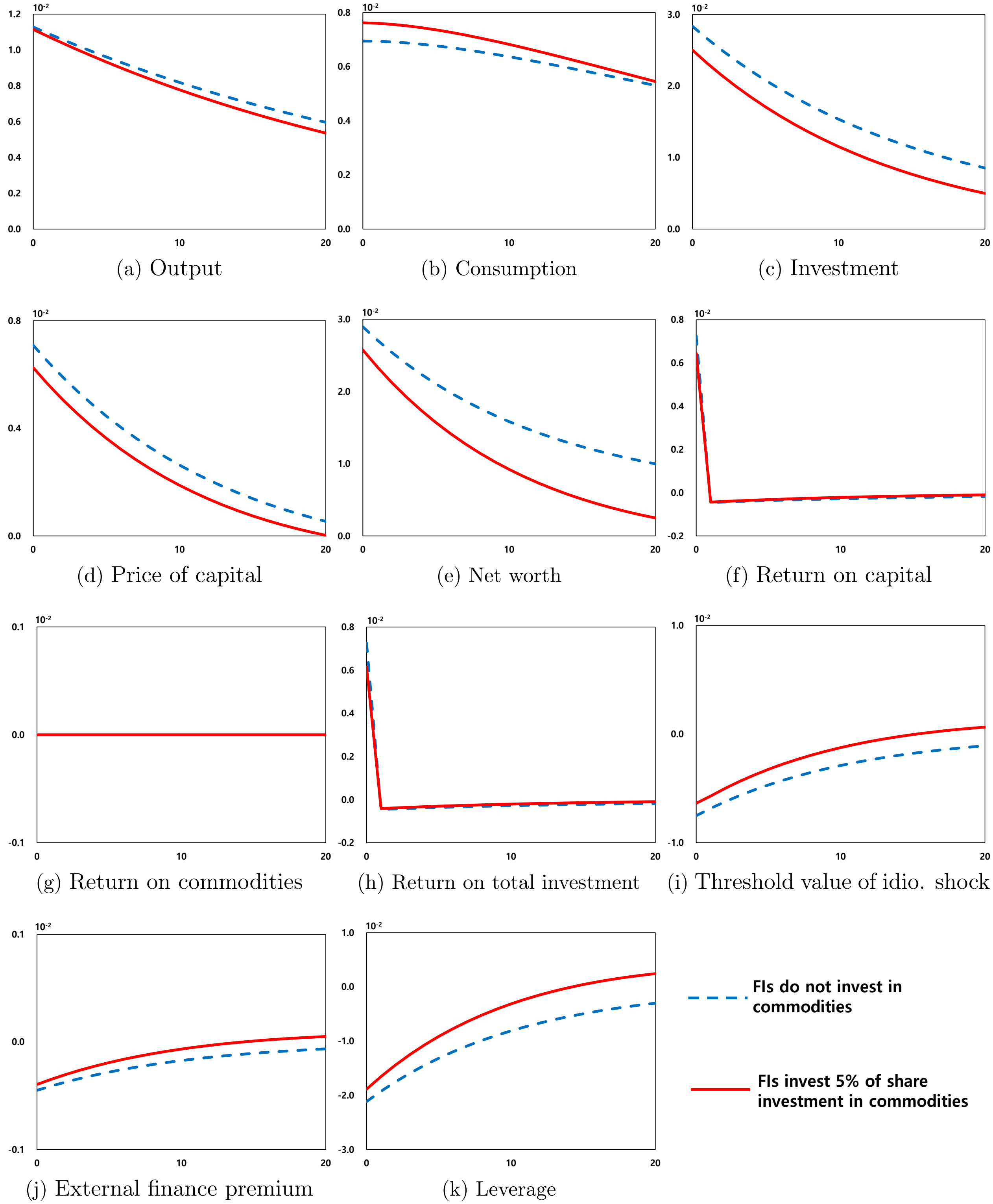
5.2.2. A positive productivity shock

In this section, I conduct a further experiment to see the responses of the model to a positive productivity shock. In the experiments hereafter, for simplicity only $\tau \in \{0, 0.05\}$ is considered. Figure 6 gives the results of this experiment.

When $\tau = 0$, a positive productivity shock increases demand for capital, which leads to an increase in Q. Thus, $R^K = R^F$ goes up initially, which brings about a decrease in $\bar{\omega}$, and thus $1 - \Gamma(\bar{\omega})$ increases. As a result, N rises, and thus investment jumps up. Consequently, output increases.

If $\tau = 0.05$, there is another effect: since R^x does not change, R^F increases less than the case of $\tau = 0$, which brings about a smaller rise in N through a smaller decrease in $\bar{\omega}$ and a smaller increase in $1 - \Gamma(\bar{\omega})$. Hence, investment rises by less than it does when $\tau = 0$, and thus output goes up by less.

In short, this experiment shows that FIs' investment in commodities dampens the impacts of a positive productivity shock on the economy. Since in the model the commodity return, which is determined exogenously, does not change in response to the shock, FIs' return on investment increases by less. Hence, FIs' net worth, investment and output go up by less if FIs hold commodities.



(a) Output
(b) Consumption
(c) Investment
(d) Price of capital
(e) Net worth
(f) Return on capital
(g) Return on commodities
(h) Return on total investment
(i) Threshold value of idio. shock
(j) External finance premium
(k) Leverage

Figure 6: Responses to a positive productivity shock

5.2.3. A positive risk shock

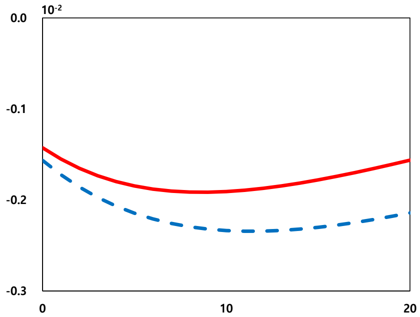
In this section I conduct an experiment which shows how the model responds to a positive risk shock.Figure 7 shows the results of this experiment.

If FIs do not invest in commodities ($\tau = 0$), a positive risk shock raises $\bar{\omega}$, which leads to a fall in $1 - \Gamma(\bar{\omega})$ and thus a decrease in N. Hence, FIs' demand for shares in capital issued by firms falls, which leads to a fall in Q, and therefore $R^K = R^F$ decreases. Accordingly, investment and output fall.

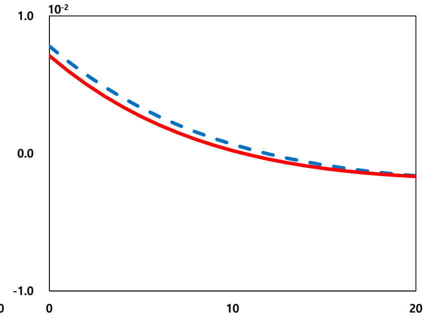
There is also another effect when $\tau = 0.05$ as in the former experiment: since CPs do not change, R^F falls by less. Thus, N drops by less through a smaller rise in $\bar{\omega}$ and a smaller fall in $1 - \Gamma(\bar{\omega})$. Therefore, investment and output decrease by less than when $\tau = 0$.

In sum, similarly to the earlier experiment, FIs' holding of commodities as an asset makes the economy less volatile to risk shocks.

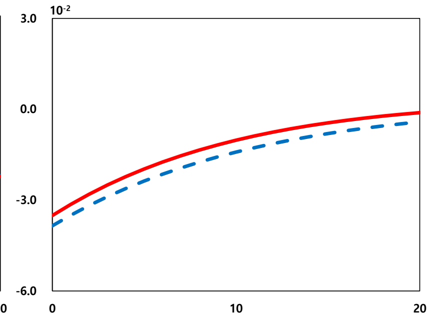
The results of the two experiments in which positive productivity and risk shocks are considered clearly show that as long as the return on commodities fluctuates less than the return on shares in capital issued by firms in response to any shocks, FIs' holding of commodities as an asset leads to smaller fluctuations in their return on total investment and net worth, and thus fluctuations in output are smaller compared to the model in which FIs do not invest in commodities. This result is very consistent with the use of commodities as a hedging instrument against equity risk.



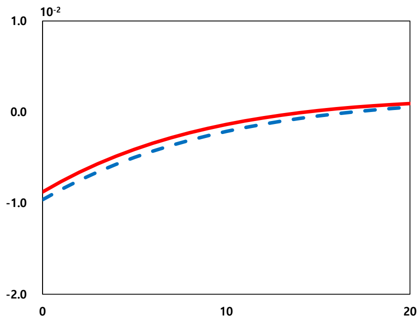
(a) Output



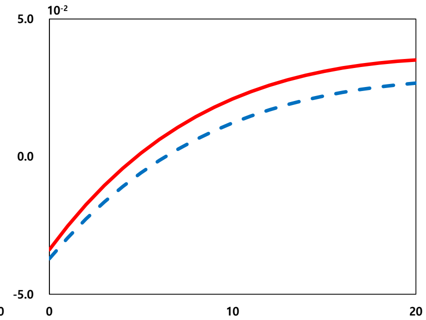
(b) Consumption



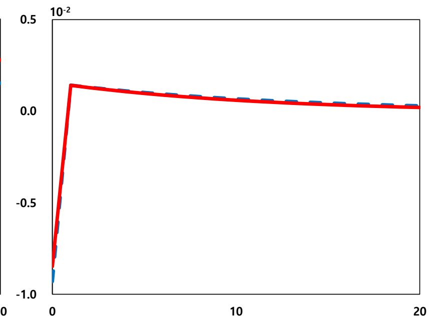
(c) Investment



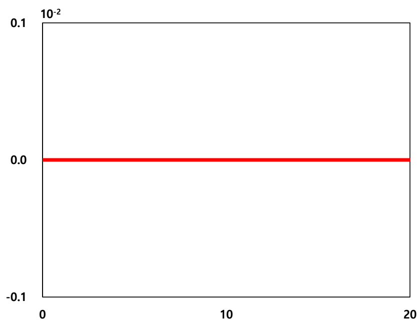
(d) Price of capital



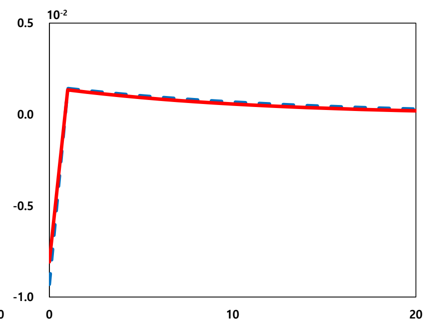
(e) Net worth



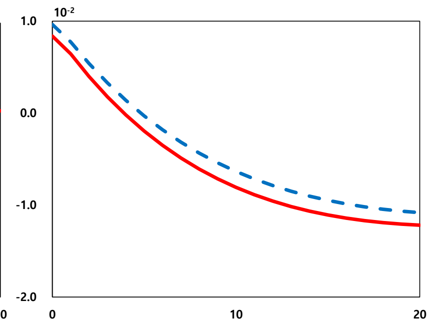
(f) Return on capital



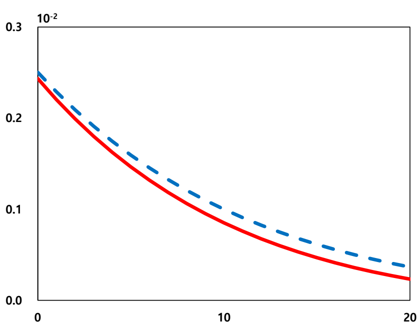
(g) Return on commodities



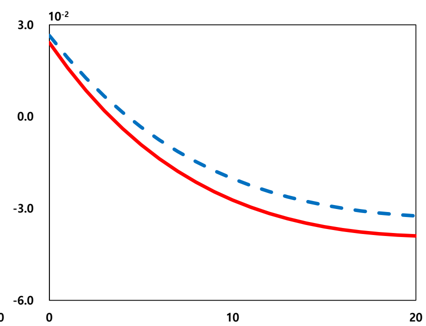
(h) Return on total investment



(i) Threshold value of idio. shock



(j) External finance premium



(k) Leverage

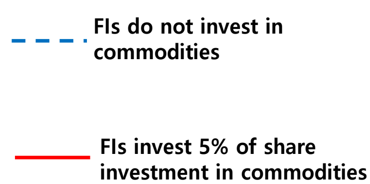


Figure 7: Responses to a positive risk shock

6. Conclusion

This chapter has developed a model with financial frictions and FIs investing in two assets tied to capital and commodities (i.e. shares in capital issued by firms and commodity derivatives) by extending the model of BGG to explain the role of commodities as an asset class in the recently declined effects of CP shocks on the economy. To do so, I simulate the responses of the variables in the model to a negative CP shock and compare them with those of a model that omits commodities as an asset class.

A negative CP shock causes both a rise in the return to FIs' investment in assets tied to capital and a fall in the return to FIs' investment in commodities. In the model in which there is no asset tied to commodities, there is only the former effect, and thus the net worth of FIs increases. However, in this model in which FIs invest in commodities as an asset, both effects exist, and therefore the net worth of FIs falls or rises by less compared to the model in which FI only hold shares in capital. Consequently, FIs' investment in shares in capital issued by firms increases by less, which brings about smaller responses of the economy to a negative CP shock, i.e. the presence of commodities as an asset class makes the economy less volatile to CP shocks.

Furthermore, according to the experiments which consider productivity and risk shocks, as long as the return on commodities fluctuates by less than the return on shares in capital, FIs' investment in commodities attenuates the impacts of any shocks on the economy through smaller fluctuations in the net worth of FIs.

Finally, in this chapter monetary and fiscal policies are omitted. However, one can include monetary and fiscal policies in the model. It would be interesting future research to study how the policy effects change and to analyse the optimal policies to CP shocks when financial frictions and commodities as an asset class are present in the model.

References

Atkeson, A. and P. J. Kehoe (1999). Models of energy use: Putty-putty versus putty-clay. *American Economic Review 89*, 1028–1043.

Basu, P. and W. T. Gavin (2011). What explains the growth in commodity derivatives? *Federal Reserve Bank of St. Louis Review 93*, 37–48.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics 1*, 1341–1393.

Blanchard, O. J. and J. Galí (2007). The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? NBER Working Paper No. 13368.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2011). Oil shocks and external adjustment. *Journal of International Economics 83*, 168–184.

Burbidge, J. and A. Harrison (1984). Testing for the effects of oil-price rises using vector autoregressions. *International Economic Review 25*, 459–484.

Castillo, P., C. Montoro, and V. Tuesta (2007). Inflation premium and oil price volatility. CEP Discussion Paper No 782, LSE.

Christiano, L. J., R. Motto, and M. Rostagno (2014). Risk shocks. *American Economic Review 104*, 27–65.

Cuñado, J. and P. d. F. Gracia (2003). Do oil price shocks matter? Evidence for some European countries. *Energy Economics 25*, 137–154.

Darrat, A. F., O. W. Gilley, and D. J. Meyer (1996). US oil consumption, oil prices, and the macroeconomy. *Empirical Economics 21*, 317–334.

Dedola, L. and G. Lombardo (2012). Financial frictions, financial integration and the international propagation of shocks. *Economic Policy 27*, 319–359.

Dhawan, R. and K. Jeske (2008). Energy price shocks and the macroeconomy: The role of consumer durables. *Journal of Money, Credit and Banking 40*, 1357–1377.

Gertler, M. and P. Karadi (2011). A model of unconventional monetary policy. *Journal of Monetary Economics 58*, 17–34.

Hamilton, J. D. (1983). Oil and the macroeconomy since world war II. *Journal of Political Economy 91*, 228–248.

Hirakata, N., N. Sudo, and K. Ueda (2009). Chained credit contracts and financial accelerators. IMES Discussion Paper 2009-E-30, Bank of Japan.

Hooker, M. A. (1996). What happened to the oil price-macroeconomy relationship? *Journal of Monetary Economics 38*, 195–213.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review 9*, 1053–1069.

Kim, I. and P. Loungani (1992). The role of energy in real business cycle models. *Journal of Monetary Economics 29*, 173–189.

Krugman, P. (2016). Oil goes nonlinear. *The New York Times*.

Leduc, S. and K. Sill (2004). A quantitative analysis of oil-price shocks, systematic monetary policy, and economic downturns. *Journal of Monetary Economics 51*, 781–808.

Luk, S. K. and D. Vines (2013). Financial-friction macroeconomics with highly leveraged financial institutions. CEPR Discussion Paper No. DP8576.

Natal, J.-m. (2012). Monetary policy response to oil price shocks. *Journal of Money, Credit and Banking 44*, 53–101.

Paul, S. and G. Mallik (2003). Macroeconomic factors and bank and finance stock prices: The Australian experience. *Economic Analysis and Policy 33*, 23–30.

Rotemberg, J. J. and M. Woodford (1996). Imperfect competition and the effects of energy price increases on economic activity. *Journal of Money, Credit and Banking 28*, 549–577.

Segal, P. (2011). Oil price shocks and the macroeconomy. *Oxford Review of Economic Policy 27*, 169–185.

Tobin, J. (1980). Stabilization policy ten years after. *Brookings Papers on Economic Activity 11*, 19–90.

Townsend, R. (1979). Optimal contracts and competitive markets with costly state verification. *Journal of Economic Theory 21*, 265–293.

Ueda, K. (2012). Banking globalization and international business cycles: Cross-border chained credit contracts and financial accelerators. *Journal of International Economics 86*, 1–16.

Wei, C. (2003). Energy, the stock market, and the putty-clay investment model. *American Economic Review 93*, 311–323.

Appendix

A. Details of the model

Analytical expressions of $\Gamma(\bar{\omega})$, $G(\bar{\omega})$ and $\Psi(\bar{\omega})$, and their derivatives By the definition of log-normal distribution, if $\ln y \sim N(c, d^2)$, $\mathbb{E}[y] = \exp[c + \frac{1}{2}d^2]$. Since $\ln\omega \sim N(-\frac{1}{2}\sigma^2, \sigma^2)$, $\mathbb{E}[\omega] = 1$.

From the definition of cumulative log-normal distribution, $F(\bar{\omega}) = \Phi(\frac{\ln\bar{\omega}+\frac{1}{2}\sigma^2}{\sigma})$, where $\Phi(\cdot)$ is the CDF of standard normal distribution. Moreover, $G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)d\omega = \mathbb{E}[\omega \mid \omega \le \bar{\omega}]\Pr(\omega \le \bar{\omega}) = \exp[-\frac{1}{2}\sigma^2 + \frac{1}{2}\sigma^2]\Phi(\frac{\ln\bar{\omega}+\frac{1}{2}\sigma^2-\sigma^2}{\sigma}) = \Phi(\frac{\ln\bar{\omega}-\frac{1}{2}\sigma^2}{\sigma})$.

Therefore, the first derivatives with respect to ω of $F(\bar{\omega})$, $\Gamma(\bar{\omega})$, $G(\bar{\omega})$ and $\Psi(\bar{\omega})$ can be obtained.

$$F_\omega(\bar{\omega}) = \frac{\partial F(\bar{\omega})}{\partial\omega} = \frac{1}{\bar{\omega}\sigma}\phi(\frac{\ln\bar{\omega}+\frac{1}{2}\sigma^2}{\sigma}) > 0 \tag{34}$$

$$G_\omega(\bar{\omega}) = \frac{\partial G(\bar{\omega})}{\partial\omega} = \frac{1}{\bar{\omega}\sigma}\phi(\frac{\ln\bar{\omega}-\frac{1}{2}\sigma^2}{\sigma}) > 0 \tag{35}$$

$$\mathit{\Gamma}_\omega(\bar{\omega}) = \frac{\partial(G(\bar{\omega}) + (1-F(\bar{\omega}))\bar{\omega})}{\partial\omega} = 1 - F(\bar{\omega}) > 0 \tag{36}$$

$$\Psi_\omega(\bar{\omega}) = \frac{\partial(\mathit{\Gamma}(\bar{\omega}) - \mu G(\bar{\omega}))}{\partial\omega} = \mathit{\Gamma}_\omega(\bar{\omega}) - \mu G_\omega(\bar{\omega}) \tag{37}$$

where $\phi(\cdot)$ is the PDF of standard normal distribution. The sign of $\frac{\partial\Psi(\bar{\omega})}{\partial\omega} = \Psi_\omega(\bar{\omega})$, however, is ambiguous. $\Psi_\omega(\bar{\omega}) = 1 - F(\bar{\omega}) - \mu\bar{\omega}f(\bar{\omega}) = (1-F(\bar{\omega}))(1-\mu\bar{\omega}h(\bar{\omega}))$, where $h(\bar{\omega}) = \frac{f(\bar{\omega})}{1-F(\bar{\omega})}$. Since $\frac{\partial\{\bar{\omega}h(\bar{\omega})\}}{\partial\bar{\omega}} > 0$, there exists $\bar{\omega}^*$ such that $\Psi_\omega(\bar{\omega}^*) = 0$. Then, $\Psi(\bar{\omega}^*)$ is the global maximum. Therefore, $\bar{\omega}^* > \bar{\omega}$, and thus $\Psi_\omega(\bar{\omega}) > 0$. The first derivatives with respect to σ of $F(\bar{\omega})$, $\Gamma(\bar{\omega})$, $G(\bar{\omega})$ and $\Psi(\bar{\omega})$ are

$$F_\sigma(\bar{\omega}) = \frac{\partial F(\bar{\omega})}{\partial\sigma} = (\frac{1}{2} - \frac{\ln\bar{\omega}}{\sigma^2})\phi(\frac{\ln\bar{\omega}+\frac{1}{2}\sigma^2}{\sigma}) \tag{38}$$

$$G_\sigma(\bar{\omega}) = \frac{\partial G(\bar{\omega})}{\partial\sigma} = -(\frac{1}{2} + \frac{\ln\bar{\omega}}{\sigma^2})\phi(\frac{\ln\bar{\omega}-\frac{1}{2}\sigma^2}{\sigma}) \tag{39}$$

$$\mathit{\Gamma}_\sigma(\bar{\omega}) = \frac{\partial(G(\bar{\omega}) + (1-F(\bar{\omega}))\bar{\omega})}{\partial\sigma} = G_\sigma(\bar{\omega}) - \bar{\omega}F_\sigma(\bar{\omega}) \tag{40}$$

$$\Psi_\sigma(\bar{\omega}) = \frac{\partial(\mathit{\Gamma}(\bar{\omega}) - \mu G(\bar{\omega}))}{\partial \sigma} = \mathit{\Gamma}_\sigma(\bar{\omega}) - \mu G_\sigma(\bar{\omega}) \tag{41}$$

Using this, the second derivatives of $\Gamma(\bar{\omega})$, $G(\bar{\omega})$ and $\Psi(\bar{\omega})$ are

$$G_{\omega\omega}(\bar{\omega}) = \frac{\partial G_\omega(\bar{\omega})}{\partial \omega} = -\left[\frac{1}{\bar{\omega}^2\sigma} + \frac{1}{\bar{\omega}^2\sigma^2}\{\frac{\ln\bar{\omega} - \frac{1}{2}\sigma^2}{\sigma}\}\right]\phi(\frac{\ln\bar{\omega} - \frac{1}{2}\sigma^2}{\sigma}) \tag{42}$$

$$\mathit{\Gamma}_{\omega\omega}(\bar{\omega}) = \frac{\partial \mathit{\Gamma}_\omega(\bar{\omega})}{\partial \omega} = -\frac{\partial F(\bar{\omega})}{\partial \omega} = -F_\omega(\bar{\omega}) \tag{43}$$

$$\Psi_{\omega\omega}(\bar{\omega}) = \frac{\partial \Psi_\omega(\bar{\omega})}{\partial \omega} = \mathit{\Gamma}_{\omega\omega}(\bar{\omega}) - \mu G_{\omega\omega}(\bar{\omega}) \tag{44}$$

$$G_{\omega\sigma}(\bar{\omega}) = \frac{\partial G_\omega(\bar{\omega})}{\partial \sigma} = -\left[1 - \frac{(\ln\bar{\omega} - \frac{1}{2}\sigma^2)^2 + \sigma^2(\ln\bar{\omega} - \frac{1}{2}\sigma^2)}{\sigma^2}\right]\frac{1}{\bar{\omega}\sigma^2}\phi(\frac{\ln\bar{\omega} - \frac{1}{2}\sigma^2}{\sigma}) \tag{45}$$

$$\mathit{\Gamma}_{\omega\sigma}(\bar{\omega}) = \frac{\partial \mathit{\Gamma}_\omega(\bar{\omega})}{\partial \sigma} = \frac{\partial(1 - F(\bar{\omega}))}{\partial \sigma} = -F_\sigma(\bar{\omega}) \tag{46}$$

$$\Psi_{\omega\sigma}(\bar{\omega}) = \frac{\partial \Psi_\omega(\bar{\omega})}{\partial \sigma} = \mathit{\Gamma}_{\omega\sigma}(\bar{\omega}) - \mu G_{\omega\sigma}(\bar{\omega}) \tag{47}$$

FI i's profit maximisation problem Since maximizing expected profit and maximizing expected logarithm of profit are identical, FI i's profit maximisation problem can be expressed by

$$\underset{\bar{\omega}_{i,t+1},\left(Q_tK_{i,t+1}+p_tx^F_{i,t}\right)}{max} \mathbb{E}_t\left[(1 - \Gamma(\bar{\omega}_{i,t+1}))R^F_{t+1}(Q_tK_{i,t+1} + p_tx^F_{i,t})\right]$$

subject to the expected participation constraint, equation (7). The corresponding Lagrangian is

$$\mathcal{L} = \mathbb{E}_t[(1 - \Gamma(\bar{\omega}_{i,t+1}))R^F_{t+1}(Q_tK_{i,t+1} + p_tx^F_{i,t}) +$$

$$\lambda_{i,t+1}\{\Psi(\bar{\omega}_{i,t+1})R^F_{t+1}(Q_tK_{i,t+1} + p_tx^F_{i,t}) - R_{t+1}(Q_tK_{i,t+1} + p_tx^F_{i,t} - N_{i,t+1})\}]$$

where λ is the Lagrange multiplier. The first order conditions are

$$\frac{\partial \mathcal{L}}{\partial \bar{\omega}_{i,t+1}} = \mathbb{E}_t\left[-\Gamma_\omega(\bar{\omega}_{i,t+1}) + \lambda_{i,t+1}\Psi_\omega(\bar{\omega}_{i,t+1})\right] = 0$$

$$\frac{\partial \mathcal{L}}{\partial \left(Q_t K_{i,t+1} + p_t x_{i,t}^F\right)} = \mathbb{E}_t \left[(1-\Gamma(\bar{\omega}_{i,t+1}))R_{t+1}^F + \lambda_{i,t+1} \left\{\Psi(\bar{\omega}_{i,t+1})R_{t+1}^F - R_{t+1}\right\}\right] = 0$$

Simplifying these two equations yields

$$\lambda_{i,t+1} = \mathbb{E}_t \left[\frac{\Gamma_\omega(\bar{\omega}_{i,t+1})}{\Psi_\omega(\bar{\omega}_{i,t+1})}\right] \tag{48}$$

$$\frac{\mathbb{E}_t[R_{t+1}^F]}{R_{t+1}} = \mathbb{E}_t \left[\frac{\lambda_{i,t+1}}{(1-\Gamma(\bar{\omega}_{i,t+1})) + \lambda_{i,t+1}\Psi(\bar{\omega}_{i,t+1})}\right] \tag{49}$$

Relation between the external finance premium and leverage From equations (9) and (10),

$$\mathbb{E}_t \left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right] = \mathbb{E}_t \left[\frac{Q_t K_{t+1} + p_t x_t^F - N_{t+1}}{\Psi(\bar{\omega}_{t+1})(Q_t K_{t+1} + p_t x_t^F)}\right] \tag{50}$$

From equation (50),

$$\frac{Q_t K_{t+1} + p_t x_t^F}{N_{t+1}} = \mathbb{E}_t \left[\frac{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})}\right] \tag{51}$$

By equations (9) and (51),

$$\frac{Q_t K_{t+1} + p_t x_t^F}{N_{t+1}} = \mathbb{E}_t \left[\frac{\{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})\}^2}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})\Gamma_\omega(\bar{\omega}_{t+1})}\right] \frac{\mathbb{E}_t[R_{t+1}^F]}{R_{t+1}} \tag{52}$$

Summary of the model The model can be summarised by following twenty four equations for twenty four variables, A, C, C^F, C_n, C_n^F, C_x, C_x^F, R, R^F, R^K, R^x, W, L_C, Y, K, x, x^F, N, Q, I, $\bar{\omega}$, σ, Z and p.[28]

$$p_t x_t^F = \tau Q_t K_{t+1} \tag{53}$$

$$R_t^F = \frac{1}{1+\tau}(R_t^K + \tau R_t^x) \tag{54}$$

$$R_t^x = \frac{p_t}{p_{t-1}} + \Delta \tag{55}$$

[28] Since FIs inelastically supply one unit of labour, $L_{F,t} = 1$ for all t.

$$Z_{t+1} = \frac{\bar{\omega}_{t+1} R^F_{t+1}(Q_t K_{t+1} + p_t x^F_t)}{Q_t K_{t+1} + p_t x^F_t - N_{t+1}} \tag{56}$$

$$\frac{\mathbb{E}_t[R^F_{t+1}]}{R_{t+1}} = \mathbb{E}_t\left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right] \tag{57}$$

$$\Psi(\bar{\omega}_t) R^F_t (Q_{t-1}K_t + p_{t-1}x^F_{t-1}) = R_t(Q_{t-1}K_t + p_{t-1}x^F_{t-1} - N_t) \tag{58}$$

$$N_{t+1} = \gamma^F (1-\Gamma(\bar{\omega}_t)) R^F_t (Q_{t-1}K_t + p_{t-1}x^F_{t-1}) + (1-\alpha)\Omega_F Y_t \tag{59}$$

$$C^F_t = (1-\gamma^F)(1-\Gamma(\bar{\omega}_t)) R^F_t (Q_{t-1}K_t + p_{t-1}x^F_{t-1}) \tag{60}$$

$$C^F_{n,t} = (1-b) C^F_t \tag{61}$$

$$C^F_{x,t} = b C^F_t p_t^{-\psi} \tag{62}$$

$$1 = \beta \mathbb{E}_t\left[\frac{C_t}{C_{t+1}} R_{t+1}\right] \tag{63}$$

$$W_t = \chi C_t L^{\varphi}_{C,t} \tag{64}$$

$$C_{n,t} = (1-b) C_t \tag{65}$$

$$C_{x,t} = b C_t p_t^{-\psi} \tag{66}$$

$$Y_t = A_t\{(1-a)K_t^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}\}^{\frac{\nu\alpha}{\nu-1}} L_{C,t}^{(1-\alpha)(1-\Omega_F)} \tag{67}$$

$$W_t = (1-\alpha)(1-\Omega_F)\frac{Y_t}{L_{C,t}} \tag{68}$$

$$R^K_t = \frac{1}{Q_{t-1}}\left\{(1-\delta)Q_t + \alpha(1-a)K_t^{-\frac{1}{\nu}} \frac{Y_t}{(1-a)K_t^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}}\right\} \tag{69}$$

$$p_t = a\alpha x_t^{-\frac{1}{\nu}} \frac{Y_t}{(1-a)K_t^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}} \tag{70}$$

$$K_{t+1} = (1-\delta)K_t + I_t - \frac{\xi}{2}\frac{(K_{t+1}-K_t)^2}{K_t} \tag{71}$$

$$Q_t = 1 - \xi + \xi\frac{K_{t+1}}{K_t} \tag{72}$$

$$Y_t = (C_{n,t} + C^F_{n,t}) + p_t(C_{x,t} + C^F_{x,t}) + I_t + p_t x_t + \mu G(\bar{\omega}_t) R^F_t (Q_{t-1}K_t + p_t x^F_t) \tag{73}$$

$$\ln \sigma_t = \Lambda + \rho_\sigma \ln \sigma_{t-1} + u_t \tag{74}$$

$$\ln A_t = \kappa + \rho_A \ln A_{t-1} + \varepsilon_t \tag{75}$$

$$\ln p_t = \rho \ln p_{t-1} + \eta_t \tag{76}$$

II. Commodities and International Business Cycles

Abstract

I introduce commodities and different commodity trade structures of countries into an otherwise standard two-country model to analyse international business cycles between the U.S. and commodity-exporting countries. In the model, only the foreign country (commodity-exporting country) produces commodities and exports them to the home country (the U.S., commodity-importing country). The model produces closer international business cycle statistics to the data than a standard model. In particular, the output correlation between the two countries increases and the consumption correlation falls compared to a standard model. Notably, unlike standard models, the model yields output correlation that exceeds the consumption correlation, which mitigates the "consumption correlation puzzle" previously noted in the literature. Commodity consumption and complementarity between commodities and noncommodity goods in consumption play key roles in generating this result.

1. Introduction

The existing literature does not specifically consider international business cycles between the U.S. and commodity-exporting countries, although they are different from those between the U.S. and commodity-importing countries. To address this shortcoming in the literature, I augment a standard two-country model with commodities and idiosyncratic commodity trade structures of countries. The model generates international business cycle statistics closer to data than a standard model by increasing the output correlation between the two countries and decreasing the consumption correlation between them. Furthermore, the model yields higher output correlation than consumption correlation, which is consistent with the ranking in the data. On the contrary, standard models typically produce the opposite prediction, which is referred in the literature as the "consumption correlation puzzle."[1] Therefore, adding commodities with consideration for different commodity trade structures of countries helps mitigate the consumption correlation puzzle.

Commodities have peculiar features compared to other tradable goods. They are used as inputs in production in almost every sector as well as consumed by households. Other tradable goods, however, are typically only consumed or only used as inputs in production in a specific sector.[2] Due to these features of commodities, changes in commodity prices affect both households and firms in the economy, which means that commodity prices have more widespread effects on the economy than prices of other tradable goods. Thus, macroeconomists have regarded changes in commodity prices as a critical source of economic fluctuations and one that can affect many countries simultaneously (Blanchard and Galí, 2007). Furthermore, each country has its own idiosyncratic commodity trade structure. For instance, countries like the U.S. are net commodity-importing countries, and countries like Canada are net commodity-exporting countries.[3] Therefore, each country will be affected by the same shock in a different way. As a result, several papers studying North-South interactions[4] such as Moutos and Vines (1989) have already emphasized that to properly capture macroeconomic interactions between countries in open economy macro models, the asymmetries of trade and production resulting from commodities should be considered.

As an illustration, output growth triggered by a certain shock in the U.S., a commodity-importing country, will increase its demand for imports of commodities for production and consumption. Accordingly, commodity prices will go up. The increased demand for im-

[1] Alternatively, the "quantity anomaly" or the "BKK puzzle."

[2] For example, energy is not only consumed but also used as inputs in all sectors. On the contrary, jeans are consumed, but not used in production (they can be used in production, but very rarely). Semiconductors are only used in production in the electronic sector, and not consumed by households.

[3] During 2006-2011 the average ratio of net commodity exports to GDP in the U.S. and Canada were -7.5% and 26.0%, respectively, according to OECD Trade in Value Added database. Following IMF's commodity price index, this chapter defines the commodity sector as agriculture, hunting, forestry, fishing, mining, quarrying, wood and basic metal industries.

[4] In these models, the "Northern" economies (i.e. the developed countries) produce industrial goods, whilst the "Southern" economies (i.e. the developing countries) produce commodities.

ports of commodities and the higher prices will have positive influences on the economies of commodity-exporting countries. Conversely, the increased commodity prices will adversely affect the economies of commodity-importing countries. Hence, U.S. GDP would be expected to have stronger positive correlations with GDPs of commodity-exporting countries than those of commodity-importing countries. There are some studies in line with this hypothesis. For instance, using a two-country dynamic stochastic general equilibrium (DSGE) model, Bodenstein, Erceg and Guerrieri (2011) conclude that an increase in oil price due to an oil demand or supply shock brings about a wealth transfer toward the oil-exporter and a fall in output in the oil-importer.[5]

In accordance with this hypothesis, the U.S. has higher positive GDP correlations with commodity-exporting countries than with commodity-importing countries in the data (see Section 2 for details). It may therefore be reasonable to analyse U.S. international business cycles with commodity-exporting countries and those with commodity-importing countries separately. Surprisingly, however, international business cycles between the U.S. and commodity-exporting countries have not specifically been analysed in the international business cycle literature, although they are significantly different from those between the U.S. and commodity-importing countries.

To analyse international business cycles between the U.S. and commodity-exporting countries, this chapter introduces commodities and different commodity trade structures into the workhorse model with nontradable goods: the two-country, two-sector real business cycle (RBC) model of Stockman and Tesar (1995), henceforth ST. The primary differences of the model from the ST model[6] are that only the foreign country produces commodities, that commodities are used as an input in the production of tradable goods, and that commodities are consumed as a complement to noncommodity consumption goods.[7]

[5] Furthermore, Chapter 3 empirically shows that an expansionary monetary policy shock in the U.S. raises the U.S. output and has more positive effects on commodity-exporting countries than on commodity-importing countries.

[6] Almost all features of the ST model are the same as the model of Stockman and Tesar (1995). The utility function of the households in the ST model is different from that in Stockman and Tesar (1995). The economy in Stockman and Tesar (1995) grows at a constant rate, while there is no growth in the ST model.

[7] The inventory or storage of commodities is not considered in the model, since omitting it may not matter greatly. See Appendix A for details.

The main goal of this chapter is to examine whether the model can replicate main properties of business cycle comovements between the U.S. and commodity-exporting countries well with focus on output and consumption correlations; (i) to show that the model yields higher output correlation between the two countries than the ST model and (ii) that the model produces higher output correlation than consumption correlation (mitigates the consumption correlation puzzle). Introducing commodities with consideration for idiosyncratic commodity trade structures of countries into the ST model can indeed help strengthen the connection between outputs in the two countries and lower the consumption correlation, and hence mitigate the consumption correlation puzzle. In the model there is complementarity between commodities and noncommodity goods in consumption; this complementarity and commodity consumption play important roles in my analysis.[8]

I now summarize my findings. As for the output correlation, positive productivity shocks in the home country bring about rises in the home country's aggregate output and its demand for imports of foreign tradable goods and commodities. Thus, the real prices of foreign tradable goods and commodities increase. The rise in home demand for imports of foreign tradable goods is offset by their increased real prices. However, this substitution effect for commodities is muted because of the complementarity between commodities and noncommodity goods in consumption. Therefore, there is a larger positive spillover to the foreign country, which raises the output correlation.

Commodity consumption, which is not in the ST model, together with the complementarity plays a key role in lowering the consumption correlation and therefore mitigating the consumption correlation puzzle. When a positive productivity shock hits the home tradable sector, home commodity consumption and real commodity prices increase, and the real price of home tradable goods falls. Foreign noncommodity consumption rises thanks to a fall in the real price of home tradable goods. Despite the rise in real commodity prices, foreign commodity consumption goes up due to the complementarity. Thus, with respect to the shock, home and foreign commodity consumptions are positively correlated. On the contrary, in

[8] There are many empirical studies showing that they are complements (see Cooper, 2003; Bodenstein, Erceg and Guerrieri, 2011; etc.).

response to a positive productivity shock in the home nontradable sector, home aggregate output and commodity consumption rise. The real prices of commodity and tradable goods produced in both countries increase, since the increased home aggregate output puts upward pressure on them. Foreign noncommodity consumption drops due to the increased real price of tradable goods. Thus, foreign commodity consumption falls as well due to the complementarity and the increased real commodity prices. Accordingly, home and foreign commodity consumptions are negatively correlated with respect to the shock. As a result, the correlation between home and foreign commodity consumptions is lower than that between home and foreign noncommodity consumptions. Hence, the existence of commodity consumption in the model and the complementarity decrease the consumption correlation compared to the ST model, which enables the output correlation to be higher than the consumption correlation in the model, i.e. the model can mitigate the consumption correlation puzzle.

Among the various literatures on international business cycles, this chapter is related to research that attempt to explain the discrepancies between the data and standard models' predictions by adding new elements under productivity shocks. The first paper on international business cycles is Backus, Kehoe and Kydland (1992), henceforth BKK. Since their seminal work, a number of papers have introduced models that can explain the discrepancies by adding non-traded goods (ST), informational frictions (Kehoe and Perri, 2002), the distribution sector (Corsetti, Dedola and Leduc, 2008, henceforth CDL), etc. Some papers have tried to find factors causing the high output correlation between countries; similar financial market structures of countries (Faia, 2007), banking globalisation (Ueda, 2012), and so on. Among these papers, the model in this chapter is closest to ST and CDL in which there are tradable and nontradable sectors and sectoral productivity shocks are used in generating international business cycle statistics.

The chapter is organised as follows. Section 2 shows the main properties of business cycle comovements between the U.S. and commodity-exporting countries. Section 3 describes the model. Calibration is also presented in this section. Section 4 presents the model analysis. I first show the business cycle statistics that the model produces. I then provide the responses of the model to productivity shocks and relate them to the "Dutch disease." Finally, I present sensitivity analysis of the model to the newly introduced features in comparison with the ST model. Section 5 concludes.

2. Properties of U.S. business cycle comovements

In this section, I first present the annual U.S. GDP correlations with GDPs of 60 major countries to identify whether U.S. GDP correlations with GDPs of commodity-exporting countries are significantly higher than those with GDPs of commodity-importing countries. Then, I show international business cycle statistics between the U.S and commodity-exporting OECD countries, and between the U.S. and commodity-importing OECD countries from annual data of 35 OECD member countries for the period of 1990-2015, and briefly explain the main properties of the former and the differences between the former and the latter with focus on the output and consumption correlations.[9]

2.1. U.S. GDP comovements with commodity-exporting countries

Since the U.S. is a large economy, changes in its demand for imports of commodities affect commodity prices. Specifically, an increase in its output will increase its demand for imports of commodities, and thus commodity prices will increase. Rises in U.S. demand for imports of commodities and commodity prices will have a positive effect on outputs in commodity-exporting countries, whilst an increase in commodity prices will adversely affect outputs in commodity-importing countries. Hence, we would expect that the U.S. will have stronger GDP comovements with commodity-exporting countries than with commodity-importing countries.

Figure 1 shows the relationship between U.S. GDP correlations with 60 major countries' GDPs and the ratios of net commodity exports to GDP of the 60 countries. However, contrary to initial expectation, there seems to be no clear relationship between the two measures.

[9] See Appendix B for details of the data.

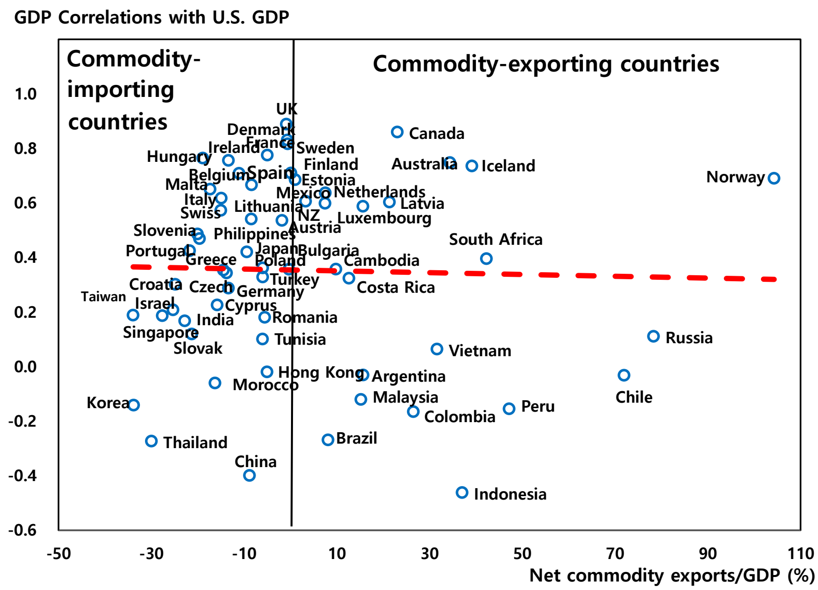
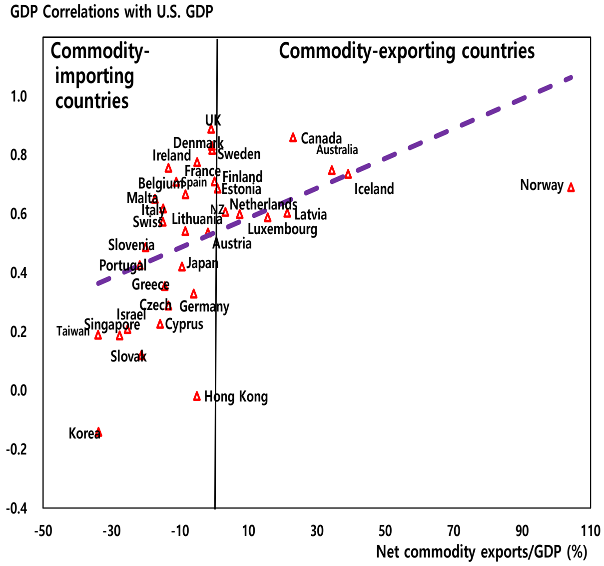


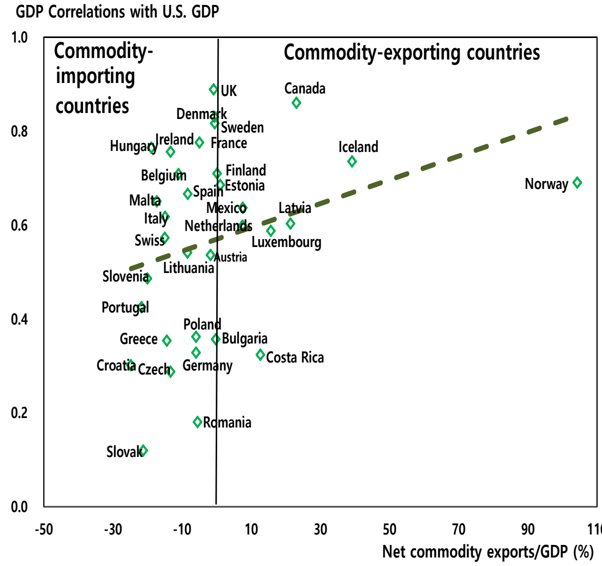
Figure 1: GDP correlations with U.S. GDP and ratios of net commodity exports to GDP

Notes: GDP correlations with U.S. GDP are calculated by using detrended annual GDPs during 1990-2015 with Hodrick-Prescott filter. The values of net commodity exports/GDP are average of the period 1995-2011. Brunei Darussalam and Saudi Arabia are omitted in this figure.
Sources: IMF and OECD

Since according to Zimmermann (1997) and Faia (2007), business cycle differences across countries can be explained by various factors such as countires' sizes and distance between countries, to analyse whether U.S. GDP correlations with commodity-exporting countries are higher than those with commodity-importing countries I control for factors other than the ratio of net commodity exports to GDP that have influences on GDP correlations. To do this, I define two groups of countries: advanced countries like the U.S., and countries in Europe or North America that are culturally and geographically close to the U.S. Figure 2 clearly shows that there is a positive relationship between GDP correlations with U.S. GDP and the ratios of net commodity exports to GDP of these groups of countries. Within these groups, U.S. GDP comovements with commodity-exporting countries are stronger than those with commodity-importing countries.



(a) Advanced countries



(b) Europe or North America

Figure 2: GDP correlations with U.S. GDP and ratios of net commodity exports to GDP

Notes: GDP correlations with U.S. GDP are calculated by using detrended annual GDPs during 1990-2015 with Hodrick-Prescott filter. The values of net commodity exports/GDP are average of the period 1995-2011. Advanced countries are based on IMF's classification. Russia and Turkey are not regarded as Europe here, since their territories are in both Europe and Asia and they are not geographically and culturally close to the U.S.
Sources: IMF and OECD

To find more accurate relationship between the U.S. GDP correlations with other countries' GDPs and the ratios of net commodity exports to GDP of the 60 countries, I conduct a simple regression following Faia (2007). As control variables, financial distance between the U.S. and the 60 countries measured by differences between banks' returns on asset as in Faia (2007), a dummy variable for English whose value is '1' if one of the country's official languages is English, the ratios of trade with the U.S. to GDP, a dummy variable for advanced country whose value is '1' if the country is included in advanced countries, and a dummy variable for region of which value is '1' if the country is in Europe or North America are used. The estimation results are presented in Table 1. The results confirm that the ratio of net commodity exports to GDP has statistically significant positive effects on U.S. GDP comovements with other countries. In other words, according to the estimation results it is statistically confirmed that the U.S. GDP correlations with GDPs of commodity-exporting countries are higher than those with GDPs of commodity-importing countries.

Table 1: Estimation results

Dependent variable: Correlation between U.S GDP and others' GDPs		
Ratio of net commodity exports to GDP	0.0014**	(0.0005)
Financial distance	-0.0247	(0.0744)
English dummy	0.2695***	(0.0763)
Ratio of trade with the U.S. to GDP	0.0003	(0.0026)
Advanced country dummy	0.1791***	(0.0671)
Region dummy	0.4447***	(0.0675)
Constant	-0.0314	(0.0790)

Note: values within parentheses are heteroscedasticity robust standard errors. ** and *** denote significant at 5% and 1%, respectively.

2.2. Main properties of U.S. business cycle comovements with commodity-exporting countries

Table 2 shows international business cycle statistics for the U.S.: the correlations between U.S. GDP, consumption and investment, and the same variables for other major countries, and commodity-exporting and commodity-importing OECD countries.

Table 2: Correlations with same U.S. variables

Variables	OECD		Commodity-exporting countries		Commodity-importing countries	
	Exporting	Importing	Australia	Canada	Japan	Germany
GDP	**0.738**	0.502	0.662	0.854	0.408	0.375
Consumption	**0.584**	0.263	0.653	0.624	-0.163	0.100
Investment	0.471	0.513	-0.098	0.634	0.687	0.340

Notes: Statistics are computed from the detrended data with Hodrick-Prescott filter. Sample period is 1990-2015. 'Exporting' and 'Importing' mean trade-weighted averages of commodity-exporting and commodity-importing OECD member countries, respectively.
Source: OECD

The correlations between U.S. GDP and GDPs in other countries are positive and high. Canada has a very large correlation, 0.854. The correlation for Japan (0.408) and Germany (0.375) are relatively small. More importantly, the correlation between U.S. GDP and GDP of commodity-exporting OECD countries (0.738) is substantially higher than that between

U.S. GDP and GDP of commodity-importing OECD countries (0.502).

U.S. consumption is also positively correlated with consumptions in other countries except Japan. However, the consumption correlations are lower than the GDP correlations. Specifically, the U.S. consumption correlations with consumptions of commodity-exporting (0.584) and commodity-importing (0.263) OECD countries are smaller than the U.S. GDP correlations with GDPs of commodity-exporting (0.738) and commodity-importing (0.502) OECD countries.

In sum, U.S. output is more strongly correlated with outputs of commodity-exporting countries than those of commodity-importing countries. The output correlation between the U.S. and commodity-exporting countries is higher than the consumption correlation between them. These are the main properties of international business cycles between the U.S. and commodity-exporting countries that the model in this chapter tries to replicate.

3. The model

In this section, I describe the two-country model with commodities in which different commodity trade structures of countries are considered. This research builds on the open economy macro models of several papers (BKK; ST; Backus and Crucini, 2000; CDL). The model is mainly based on ST. I only add commodities to the two-country, two-sector RBC model of ST.

To be specific, there are two countries: the home country (the U.S.) and the foreign country (commodity-exporting countries). The home country produces tradable and nontradable goods and imports commodities, while the foreign country produces commodities as well as tradable and nontradable goods and exports commodities. Capital is sector-specific. Labour is mobile between sectors but immobile between countries. Asset markets are complete.

The main differences of this model from ST are that commodities as a complement to noncommodity goods are in the consumption basket of households, that commodities are used in the production of tradable goods as an input, and that the foreign country produces commodities whilst the home country does not.

I next explain the details of the model.[10] I focus on the equations for the home country. Unless stated otherwise, there are symmetric equations for the foreign country.

3.1. Households

The representative household in each country maximises the following utility.

$$U = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \frac{L_t^{1+\chi}}{1+\chi} \right) \tag{1}$$

where $\mathbb{E}_0$ is the conditional expectations operation, C_t is the composite of tradable, nontradable and commodity consumption goods, L_t is labour supply by households, β is the discount factor, and χ is the inverse of Frisch elasticity of labour supply.

The budget constraint[11] is

$$C_t + p_{H,t} I_{T,t} + p_{N,t} I_{N,t} + \mathbb{E}_t\{\mathcal{Q}_{t,t+1} D_{t+1}\} = W_{T,t} L_{T,t} + W_{N,t} L_{N,t} + r_{T,t} K_{T,t} + r_{N,t} K_{N,t} + D_t + \mathit{\Pi}_t \tag{2}$$

with $L_t = L_{T,t} + L_{N,t}$. $\mathcal{Q}_{t,t+1}$, D_{t+1}, W_t and $\mathit{\Pi}_t$ denote the stochastic discount factor for one-period ahead real pay-offs relevant to the home household, the real pay-off in period $t+1$ of the portfolio held at the end of period t, the real wage and the profits remitted by firms, respectively. The subscripts 'T', 'N' and 'X' denote the tradable, nontradable and commodity sectors, respectively, and the subscripts 'H' and 'F' mean the tradable goods produced in the home and foreign countries, respectively. p, I, K and r are the real prices of goods, the investment, the capital and the real rental rate of capital, respectively.

The law of motion for capital in each sector is given by:

$$K_{j,t+1} = (1-\delta) K_{j,t} + I_{j,t}, \;\; j \in \{T, N, X\} \tag{3}$$

The composite of consumption goods, C_t, is defined as the following constant elasticity

[10] For the equilibrium conditions of the model, see Appendix C.

[11] Since the commodity sector exists in the foreign country, the household's budget constraint in the foreign country is $C_t^* + p_{F,t}^* I_{T,t}^* + p_{N,t}^* I_{N,t}^* + p_{X,t}^* I_{X,t}^* + \mathbb{E}_t\{\mathcal{Q}_{t,t+1}^* D_{t+1}^*\} = W_{T,t}^* L_{T,t}^* + W_{N,t}^* L_{N,t}^* + W_{X,t}^* L_{X,t}^* + r_{T,t}^* K_{T,t}^* + r_{N,t}^* K_{N,t}^* + r_{X,t}^* K_{X,t}^* + D_t^* + \mathit{\Pi}_t^*$ with $L_t^* = L_{T,t}^* + L_{N,t}^* + L_{X,t}^*$. The superscript '$*$' denotes the variables in the foreign country.

of substitution (CES) aggregator function of noncommodity consumption goods, $C_{NC,t}$, and commodity consumption goods, $C_{X,t}$.

$$C_t = \left\{ (1-\gamma_0)^{\frac{1}{\eta_0}} C_{NC,t}^{\frac{\eta_0-1}{\eta_0}} + \gamma_0^{\frac{1}{\eta_0}} C_{X,t}^{\frac{\eta_0-1}{\eta_0}} \right\}^{\frac{\eta_0}{\eta_0-1}} \tag{4}$$

The noncommodity consumption goods, in turn, are similarly defined by tradable, $C_{T,t}$, and nontradable consumption goods, $C_{N,t}$:

$$C_{NC,t} = \left\{ (1-\gamma_1)^{\frac{1}{\eta_1}} C_{T,t}^{\frac{\eta_1-1}{\eta_1}} + \gamma_1^{\frac{1}{\eta_1}} C_{N,t}^{\frac{\eta_1-1}{\eta_1}} \right\}^{\frac{\eta_1}{\eta_1-1}} \tag{5}$$

The tradable consumption goods consist of tradable consumption goods produced in the home country, $C_{H,t}$, and tradable consumption goods produced in the foreign country, $C_{F,t}$.

$$C_{T,t} = \left\{ (1-\gamma_2)^{\frac{1}{\eta_2}} C_{H,t}^{\frac{\eta_2-1}{\eta_2}} + \gamma_2^{\frac{1}{\eta_2}} C_{F,t}^{\frac{\eta_2-1}{\eta_2}} \right\}^{\frac{\eta_2}{\eta_2-1}} \tag{6}$$

The corresponding price indices, P_t (CPI), $P_{NC,t}$ (price of noncommodity consumption goods) and $P_{T,t}$ (price of tradable consumption goods), are following.[12]

$$P_t = \left\{ (1-\gamma_0) P_{NC,t}^{1-\eta_0} + \gamma_0 P_{X,t}^{1-\eta_0} \right\}^{\frac{1}{1-\eta_0}} \tag{7}$$

$$P_{NC,t} = \left\{ (1-\gamma_1) P_{T,t}^{1-\eta_1} + \gamma_1 P_{N,t}^{1-\eta_1} \right\}^{\frac{1}{1-\eta_1}} \tag{8}$$

$$P_{T,t} = \left\{ (1-\gamma_2) P_{H,t}^{1-\eta_2} + \gamma_2 P_{F,t}^{1-\eta_2} \right\}^{\frac{1}{1-\eta_2}} \tag{9}$$

where $P_{X,t}$ is the price of commodity consumption goods, $P_{N,t}$ is the price of nontradable consumption goods, $P_{H,t}$ is the price of tradable consumption goods produced in the home country, and $P_{F,t}$ is the price of tradable consumption goods produced in the foreign country.

[12] The uppercase letter P denotes nominal prices.

3.2. Firms

Nontradable good and commodity producers use labour and capital as inputs for the productions, while tradable good producers use commodities as well as labour and capital in production. Both countries produce tradable and nontradable goods with the same production function, but only the foreign country produces commodities.

Nontradable good producers

Nontradable good producers use labour and capital in production, and both countries produce nontradable goods with the identical production function.

$$Y_{N,t} = A_{N,t} K_{N,t}^{\alpha_N} L_{N,t}^{1-\alpha_N} \tag{10}$$

where $Y_{N,t}$ is the output of nontradable goods, $A_{N,t}$ is the productivity in the nontradable production, $K_{N,t}$ is the capital used in the nontradable production, $L_{N,t}$ is the labour, and $1 - \alpha_N$ is the labour share of income.

Tradable good producers

Both countries produce tradable goods by using capital, labour and commodities as inputs. The production function of tradable goods is a nested CES as in Kim and Loungani (1992) and Backus and Crucini (2000).

$$Y_{H,t} = A_{T,t} \{(1-a) K_{T,t}^{\frac{\nu-1}{\nu}} + a x_t^{\frac{\nu-1}{\nu}}\}^{\frac{\nu\alpha}{\nu-1}} L_{T,t}^{1-\alpha} \tag{11}$$

where $Y_{H,t}$, $A_{T,t}$, $K_{T,t}$, x_t and $L_{T,t}$ denote the output, productivity, capital, commodities and labour for the production of tradable goods, respectively. $1-\alpha$ is the labour share of income. a and ν determine the importance of commodities and the elasticity of substitution between capital and commodities.

Commodity producers

Commodity producers use capital and labour as inputs in production, and only the foreign country produces commodities. The production function is Cobb-Douglas as in Arora and Gomis-Porqueras (2011) and Huynh (2016).[13]

$$Y^*_{X,t} = A^*_X {K^*_{X,t}}^{\alpha_X} {L^*_{X,t}}^{1-\alpha_X} \tag{12}$$

where $Y^*_{X,t}$, A^*_X, $K^*_{X,t}$ and $L^*_{X,t}$ are the output, productivity, capital and labour for the commodity production, respectively. $1-\alpha_X$ is the labour share of income.

3.3. Resource constraints

Since output in the nontradable sector in the home country has to be the same as home country's demand for nontradable goods and its investment and output in the tradable sector in the home country must equal the world demand for the tradable goods produced in the home country and its investment, the resource constraints of the home country can be written as:[14]

$$Y_{N,t} = C_{N,t} + I_{N,t} \tag{13}$$

$$Y_{H,t} = C^*_{H,t} + C_{H,t} + I_{T,t} \tag{14}$$

3.4. Calibration

Table 3 lists the parameter values for the model which are based on U.S. annual data. I assume symmetry between the two countries following standard international business cycle literature such as BKK, ST and CDL, with exception of the commodity sector.

[13] Some papers such as Bodenstein, Erceg and Guerrieri (2011) assume that commodities are endowments rather than goods produced. If commodities are endowments, commodity prices should be exogenous. However, the important channel for changes in commodity prices and output in the commodity sector to respond to productivity shocks in the model will be omitted if commodity prices are exogenous (see Section 4 for details). Therefore, I assume that the commodities are produced rather than being endowments.

[14] Since output in the commodity sector in the foreign country should be equal to the world demand for commodities and its investment, the resource constraint of the commodity sector in the foreign country is $Y^*_{X,t} = C_{X,t} + C^*_{X,t} + x_t + x^*_t + I^*_{X,t}$.

Table 3: Parameter values

Parameter	Value	Definition
β	0.96	Discount factor
χ	3	Inverse of Frisch elasticity of labour supply
δ	0.1	Depreciation rate of capital
$1-\alpha_N$	0.56	Labour share in the nontradable sector
$1-\alpha$	0.61	Labour share in the tradable sector
ν	1	Elasticity of substitution between commodities and capital in the tradable production
a	0.1823	Parameter related to the weight of commodities in the tradable production
$1-\alpha_X$	0.66	Labour share in the commodity sector
γ_0	0.112	Weight of commodities in the composite of consumption goods
η_0	0.3	Elasticity of substitution between commodity and noncommodity consumption goods
γ_1	0.5631	Weight of nontradable goods in the noncommodity consumption goods
η_1	0.44	Elasticity of substitution between tradable and nontradable goods
γ_2	0.3557	Weight of foreign tradable goods in the tradable consumption goods in the home country
γ_2^*	0.7749	Weight of home tradable goods in the tradable consumption goods in the foreign country
η_2	1.1	Elasticity of substitution between home and foreign tradable goods

I borrow certain parameter values from the standard literature. The discount factor, β, is 0.96 following ST and CDL. The inverse of Frisch elasticity of labour supply, χ, is set to 3 as in Galí and Monacelli (2005). The depreciation rates of capitals for the tradable and nontradable productions, δ, are 0.1 as in ST and CDL. I assume that the depreciation rate of capital for the commodity production is also 0.1 as in Arora and Gomis-Porqueras (2011) and Huynh (2016), using the same depreciation rate of capital for energy production as in the production in other sectors. Following ST, I set the labour shares of income in the nontradable $(1-\alpha_N)$ and tradable $(1-\alpha)$ sectors at 0.56 and 0.61 respectively.

The elasticity of substitution between capital and commodities in the tradable production, ν, is 1 following Kim and Loungani (1992). They consider two cases, $\nu = 1$ and $\nu = 0.588$. They refer to the former case as the "Cobb-Douglas" case and the latter as the "CES" case. Considering that the Cobb-Douglas case replicates the business cycle data better than the CES case in Kim and Loungani (1992), this model uses $\nu = 1$. Nevertheless, since ν is a new parameter from the introduction of commodities to the ST model, various values of ν ranging from 0.5 to 1 based on previous studies are examined to check whether changes in ν lead to different simulation results of the model. I assume that the steady state capital/commodity ratio in the tradable production, K_T/x, is 31.55 which is different from Kim and Loungani

(1992) and others.[15] Kim and Loungani (1992) use a value of 50 as the ratio. However, in this model, firms use all types of commodities rather than only energy. Because the weight of energy in the IMF's commodity price index is 0.631, 50×0.631=31.55 as the steady state capital/commodity ratio is appropriate. The parameter related to the weight of commodities in the tradable production, a, is set to 0.1823. This value is determined by the values of ν, K_T/x, β and δ.[16] Based on the assumption that real wage in each sector is identical in the model due to labour mobility between sectors, the labour share of income in the commodity sector, $1-\alpha_X$, is set to 0.66. These parameter values are consistent with the steady state ratio of investment to output in each sector, $I_N/Y_N = 0.31$ and $I_T/Y_H = 0.23$, and the steady state ratio of aggregate investment to aggregate output, $I/Y = 0.27$ which is close to the value in the standard RBC literature (0.25). Accordingly, the steady state ratio of output in the nontradable sector to aggregate output, Y_N/Y, is 0.51 which closely matches the average ratio of output in the service sector[17] to GDP for 1997-2015[18] from the NIPA data (0.54).[19]

The parameters associated with consumption are as follows. The weight of commodity consumption goods in the composite of consumption goods, γ_0, is set to 0.112 which is consistent with the NIPA data, the average ratio of commodity consumption[20] to total consumption for 1990-2015. Since γ_0 is newly introduced due to the commodity consumption, various values of γ_0, from the minimum (0.1) to maximum (0.13) for 1990-2015, are examined in the sensitivity analysis. The elasticity of substitution between commodity and noncommodity consumption goods, η_0, is 0.3 following Natal (2012). Because η_0 does not appear in the ST model, a variety of values of η_0 in previous studies, from 0.1 to 1, are used

[15] Variables without time subscript 't' denote their steady state values.

[16] From the first order conditions of households and firms in steady state, $a = \frac{1}{1+(1/\beta-1+\delta)(K_T/x)^{\frac{1}{\nu}}}$.

[17] I take the service sector to be wholesale and retail trades, transportation and warehousing, finance, insurance, real estate, rental, leasing, professional and business services, educational services, health care, social assistance, arts, entertainment, recreation, accommodation, food services, and other services (except government).

[18] Because the NIPA data on real gross output by industry is only available from 1997, I use the data for 1997-2015.

[19] Since both countries have identical tradable and nontradable sectors, I_N^*/Y_N^* and I_T^*/Y_F^* are the same as those in the home country. For the foreign commodity sector, the values of α_X, δ and β are consistent with $I_X^*/Y_X^* = 0.24$. Foreign commodity output is determined by the market clearing condition, which implies $Y_N^*/Y^* = 0.52$, $Y_F^*/Y^* = 0.21$ and $Y_X^*/Y^* = 0.28$.

[20] Gasoline and other energy goods, plus food and beverages purchased for off-premises consumption

to see whether the main results of this chapter are sensitive to change in η_0. The weight of nontradable consumption goods in the noncommodity consumption goods, γ_1, is 0.5631 which is different from ST. Since commodities are part of tradable goods in ST, γ_1=0.5631 is consistent with the ST's assumption that the steady state ratio of consumption of all tradable goods (commodities and tradable goods in the model) to nontradable consumption is 1. The elasticity of substitution between tradable and nontradable consumption goods, η_1, is 0.44 which is borrowed from ST. The weight of tradable consumption goods produced in the foreign country in the tradable consumption goods in the home country, γ_2, is 0.3557. Considering that commodities are also tradable goods, under γ_2=0.3557 the steady state ratio of imported commodity and tradable consumption goods to total tradable consumption goods in the home country is 0.5, i.e. $(C_X + C_F)/(C_T + C_X) = 0.5$. This ratio is consistent with ST in which the steady state ratio of imported tradable consumption goods to total tradable consumption goods is 0.5. The weight of tradable consumption goods produced in the home country in the tradable consumption goods in the foreign country, γ_2^*, is 0.7749, which is a result of the assumptions that in the steady state households' labour supply in the home country is the same as that in the foreign country ($L = L^*$) and that the steady state values of aggregate consumptions in both countries are equal ($C = C^*$). Under these assumptions, from the first order condition of households' problems in steady state, the steady state real wages in both countries are equal. The elasticity of substitution between home and foreign tradable consumption goods, η_2, is set to 1.1 following Bodenstein, Erceg and Guerrieri (2011). These parameter values are set to equate the steady state ratio of aggregate consumption to aggregate output in the home country, C/Y, to 0.7 which is the same as the value in the standard RBC literature (0.7) and close to the average ratio of private consumption expenditure to GDP for 1990-2015 from the NIPA data (0.66). This implies that $C^*/Y^* = 0.71$.

Finally, productivities in the tradable and nontradable sectors in the home and the foreign countries follow AR(1) process as in BKK, ST and CDL.

$$\mathbb{A}_t = \rho \mathbb{A}_{t-1}^T + \varepsilon_t \tag{15}$$

where $\mathbb{A}_t = [A_{T,t}, A^*_{T,t}, A_{N,t}, A^*_{N,t}]^T$ and $\varepsilon_t = [e_{T,t}, e^*_{T,t}, e_{N,t}, e^*_{N,t}]^T$ is the vector of productivity shocks. As in BKK and CDL, to estimate the process I use annual data of "Index of output per hour in manufacturing" and "Index of output per hour in private services" for the period 1970-2015 from BLS as the productivities in the home tradable and nontradable sectors, and as the productivities in the foreign tradable and nontradable sectors average of commodity-exporting OECD countries' indices of manufacturing output and output in services divided by sectoral total employment for the period 1970-2015 from the OECD STAN sectoral database are used.[21] The coefficient matrix, ρ, and the variance-covariance matrix of productivity shocks, $Var(\varepsilon_t)$ (in per cent), are

$$\rho = \begin{pmatrix} 0.85 & -0.05 & 0.10 & 0.16 \\ -0.05 & 0.85 & 0.16 & 0.10 \\ 0.01 & -0.04 & 0.94 & 0.01 \\ -0.04 & 0.01 & 0.01 & 0.94 \end{pmatrix}, \quad Var(\varepsilon_t) = \begin{pmatrix} 0.0463 & 0.0067 & 0.0027 & 0.0014 \\ 0.0067 & 0.0463 & 0.0014 & 0.0027 \\ 0.0027 & 0.0014 & 0.0036 & 0.0004 \\ 0.0014 & 0.0027 & 0.0004 & 0.0036 \end{pmatrix}$$

The values for the elements in the above matrices are similar to those in CDL.

4. Model analysis

In this section, I further assume that the productivity in the commodity production is fixed, while the productivities in the tradable and nontradable sectors are stochastic as in ST. This is because the main aim of this chapter is to show that instead of adding additional shocks, adding commodities and idiosyncratic commodity trade structures of countries to the ST model can help produce better international business cycle statistics compared to the ST model.

[21] The data for the Netherlands and Norway is used for the estimation, since the data for other commodity-exporting OECD countries is not available for the period.

4.1. International business cycles

Table 4 shows the business cycle statistics from the model and the ST model (model without commodities) driven by productivity shocks, in terms of the relative standard deviations to output in the home country, correlations with output in the home country, and correlations between the home and the foreign countries. Nonetheless, since the main aim of this chapter is to show that the output correlation in the model is higher than the consumption correlation in the model and the output correlation in the ST model, I focus on the output and consumption correlations between the two countries.

The ST model is unsuccessful in replicating the main properties of international business cycles between the U.S. and commodity-exporting countries explained in Section 2. Specifically, the output correlation between the two countries is too low compared to the data. The consumption correlation between the two is too high and greater than the output correlation. These are very different from the data, but typical in open economy macro models.

The model, however, produces much closer international business cycle statistics to the data than the ST model.

Table 4: Business cycle statistics

Statistics	Data	Model	Model without commodities
S.D. relative to GDP in home			
Consumption	0.986	0.457	0.432
Investment	3.389	3.059	2.622
Real net exports over GDP	0.361	0.135	0.042
Correlation with GDP in home			
Consumption	0.938	0.849	0.803
Investment	0.957	0.985	0.977
Real net exports over GDP	-0.766	-0.969	0.067
Correlation between home and foreign			
GDP	0.738	**0.789**	0.658
Consumption	0.584	**0.740**	0.774
Investment	0.471	0.638	0.531

Notes: The correlation between home and foreign from the data is trade-weighted average correlation between the same variables of the U.S. and commodity-exporting OECD countries. Sample period is 1990-2015.
Source: OECD

Specifically, the output correlation in the model is higher than that in the ST model and closer to the data. This result is consistent with the empirical finding in Section 2 that GDPs of commodity-exporting countries are more positively correlated with the U.S. GDP than those of commodity-importing countries. The consumption correlation decreases compared to the ST model. As a result, in the model the output correlation is greater than the consumption correlation, i.e. the consumption correlation puzzle is mitigated. In short, the model produces better business cycle comovements between the U.S. and commodity-exporting countries in terms of the output and consumption correlations compared to the ST model.

Although full international risk sharing which would lead the consumption correlation to be very high and close to 1 holds in this chapter due to the assumption of complete asset markets, the consumption correlations in the model and the ST model are substantially lower than 1, although still high. In contrast, the model of BKK, in which all consumptions goods are tradable and complete asset markets are assumed, generates very high consumption correlation (0.88). By including nontradable goods which are complements to tradable goods, the ST model yields lower consumption correlation than that of BKK, since a positive productivity shock to the nontradable sector in one country increases its aggregate consumption without causing a rise in the aggregate consumption of the other country.[22] This chapter shows that including commodities in consumption which are complements to noncommodity goods and only produced by one country helps to reduce consumption correlation.[23]

As for other business cycle statistics, overall the model generates better business cycle statistics than the ST model, although it produces worse correlations between home output and investment, and between the two countries' investments; the standard deviations of consumption, investment and real net exports over GDP relative to GDP in the home country and the correlations of consumption and net exports over GDP with GDP in the home country

[22] A positive productivity shock to the home nontradable sector increases home nontradable consumption and lowers its real price, which raises the real price of tradable goods. Due to the complementarity between tradable and nontradable goods in consumption, home tradable consumption rises in spite of an increase in the real price of tradable goods. Accordingly, home aggregate consumption increases. Since the real price of tradable goods increases, foreign consumption of tradable goods falls, which leads to a decrease in foreign consumption of nontradable goods owing to the complementarity. As a consequence, foreign aggregate consumption goes down.

[23] The reason for this is explained in the next section.

are all improved compared to the ST model.

Finally, it should be noted that these results cannot be of general application to all countries. These results can instead be only applied to international business cycles between the U.S. and commodity-exporting countries.

4.2. Features of the model generating the output and consumption correlation outcomes

In this section, I explain how the model generates better international business cycle statistics than the ST model with focus on the output and consumption correlations. Better international business cycle statistics in the model compared to the ST model are primarily because of the complementarity between commodity and noncommodity consumption goods and commodity consumption, which is not present in the ST model.

With regard to the output correlation, positive productivity shocks in the home country raise its aggregate output and consumption, which leads to an increase in its demand for imports of foreign tradable goods and commodities. The increased demand causes rises in the real prices of foreign tradable goods and commodities. The rise in home demand for imports of foreign tradable goods is offset by their increased real prices. For commodities, however, although real commodity prices increase, the home country imports more commodities thanks to the complementarity between commodity and noncommodity consumption goods ($\eta_0 < 1$). Therefore, output in the foreign commodity sector rises, and thus there is a larger positive spillover to the foreign country compared to the ST model in which the foreign country does not have the commodity sector. As a result, the output correlation in the model becomes greater than that in the ST model.

With regard to the consumption correlation, when a positive productivity shock hits the home tradable sector, home commodity consumption and real commodity prices rise, and the real price of home tradable goods falls. The decrease in the real price of home tradable goods leads to a fall in the real price of tradable goods in the foreign country. Foreign noncommodity consumption increases due to the fall in the real price of tradable goods.

Despite the rise in real commodity prices, foreign commodity consumption goes up owing to the complementarity between commodity and noncommodity consumption goods. On the contrary, in response to a positive productivity shock in the home nontradable sector, home aggregate output and commodity consumption increase. The real prices of commodities and tradable goods produced in both countries go up, because the increased home aggregate output puts upward pressure on them. Foreign noncommodity consumption goes down owing to the increased real price of tradable goods. Thus, foreign commodity consumption falls due to the complementarity and increased real commodity prices. In other words, home and foreign commodity consumptions are positively correlated with respect to productivity shocks in the tradable sector, whilst they are negatively correlated with respect to productivity shocks in the nontradable sector. This negative correlation with respect to productivity shocks in the nontradable sector enables the correlation between home and foreign commodity consumptions[24] to be lower than that between home and foreign noncommodity consumptions in the model. Therefore, the model generates lower consumption correlation compared to the ST model in which there is no commodity consumption.

4.3. Impulse responses

In order to understand how the model yields better international business cycle statistics in a more straightforward manner, I conduct impulse response analysis to productivity shocks in this section. Specifically, I study how variables in the model and the ST model respond to either a positive 1% tradable or nontradable productivity shock in the home country, with focus on outputs and consumptions. In addition, for deeper intuition, I relate the impulse responses of the foreign country to a shock raising foreign commodity output to the Dutch disease. For simplicity, I abstract from the productivity spillover implied in the coefficient matrix of productivities and variance-covariance matrix of productivity shocks only in impulse

[24] Since productivity shocks to the nontradable sector are far weaker than those to the tradable sector as usually shown in previous studies, the consumption correlation between home and foreign commodity consumptions is positive. The standard deviation of the latter is about 3.5 times larger than the former which is implied in variance-covariance matrix of productivity shocks, $Var(\varepsilon_t)$.

responses, i.e. the off-diagonal elements of ρ and $Var(\varepsilon_t)$ are all zero.[25]

4.3.1. A positive 1% productivity shock in the home tradable sector

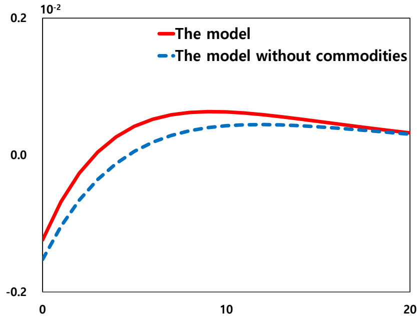
Figure 3 shows the responses of the model and the ST model (the model without commodities) to a positive 1% productivity shock in the home tradable sector.

First, consider the home country. In both models, a positive productivity shock in the home tradable sector increases output, Y_H, and consumption, C_H, in the sector and decreases the real price of tradable goods in the home country, p_T, mainly due to a large fall in the real price of tradable goods produced in the home country, p_H. However, the increase in Y_H in the ST model is greater than that in the model. This is because, differently from the ST model, in the model an increase in Y_H puts upward pressure on demands for commodities as well as nontradable goods, which raises real commodity prices, p_X and p_X^*, and the real price of nontradable goods, p_N. Since commodities are used in the production of tradable goods as an input, a rise in p_X means an increase in the marginal costs of the firms in the tradable sector. Thus, the shock has a slightly bigger positive effect on Y_H in the ST model which does not have commodities than in the model. Nevertheless, consumption of tradable goods, C_T, in the model rises by more than that in the ST model due to a bigger fall in p_T. Because in the model due to commodities $P_t = \left\{(1-\gamma_0)P_{NC,t}^{1-\eta_0} + \gamma_0 P_{X,t}^{1-\eta_0}\right\}^{\frac{1}{1-\eta_0}}$, which can be expressd as $1 = (1-\gamma_0)p_{NC,t}^{1-\eta_0} + \gamma_0 p_{X,t}^{1-\eta_0}$ by dividing by $P_t^{1-\eta_0}$, and p_X goes up, the real price of noncommodity goods, p_{NC}, falls. In the model $p_{NC,t}^{1-\eta_1} = (1-\gamma_1)p_{T,t}^{1-\eta_1} + \gamma_1 p_{N,t}^{1-\eta_1}$, whilst in the ST model which does not have commodities $1 = (1-\gamma_1)p_{T,t}^{1-\eta_1} + \gamma_1 p_{N,t}^{1-\eta_1}$. Therefore, p_N in the model increase by less than that in the ST model, but p_T in the model falls by more than that in the ST model. Despite the increased p_N, consumption of nontradable goods, C_N, in the model rises slightly thanks to the complementarity between C_T and C_N ($\eta_1 < 1$). On the contrary, C_N in the ST model goes down slightly, since in spite of the complementarity a rise in C_T is smaller and an increase in p_N is bigger compared to the model. Hence, a fall in output in the nontradable sector, Y_N, in the model is smaller than

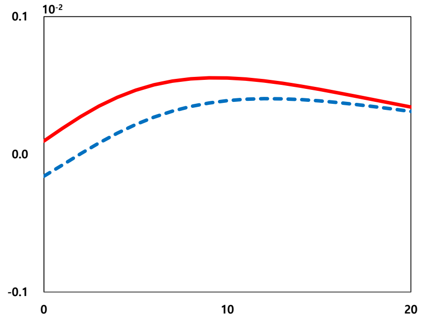
[25] Impulse response analysis with the productivity spillover results in all shocks hitting at the same time, which makes it hard to understand how a certain variable in the model responds to a certain shock.

the ST model. Because of rises in C_T and C_N, noncommodity consumption, C_{NC}, increases, which leads to a rise in commodity consumption, C_X, in the model despite the increased p_X due to the complementarity between C_{NC} and C_X ($\eta_0 < 1$). A rise in Y_H leads to an increase in demand for commodities in the production in the home tradable sector, x. Finally, from $p_{T,t}^{1-\eta_2} = (1-\gamma_2)p_{H,t}^{1-\eta_2} + \gamma_2 p_{F,t}^{1-\eta_2}$, since p_T in the model goes down by more than that in the ST model, p_H in the model fall by more compared to the ST model. Hence, the rise in C_H in the model is greater than the ST model. Due to a larger fall in p_H than p_F, consumption of foreign tradable goods, C_F, drops. Overall, aggregate output and consumption in the home country, Y and C, increase, and the increase in Y of the model is smaller than that of the ST model while the increase in C of the model is bigger than that of the ST model.

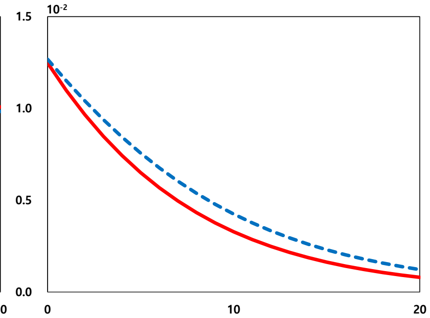
As for the foreign country, a fall in p_T and a rise in p_F lead to a decrease in p_T^* and an increase in p_F^*, respectively. Since the fall in p_T and the rise in p_F in the model are bigger than those in the ST model, the decrease in p_T^* and the increase in p_F^* in the model are also larger than those in the ST model. Thus, C_T^* in the model jumps by more than that in the ST model, and C_F^* in the model drops by more than that in the ST model, which brings about a greater fall in Y_F^* in the model compared to that in the ST model. Since p_T^* in the model decreases by more than that in the ST model, a rise in p_N^* in the model is larger than that in the ST model. In spite of an increase in p_N^*, C_N^* rises thanks to the complementarity between C_T^* and C_N^*. Despite a greater increase in C_T^* in the model, a bigger rise in p_N^* in the model compared to the ST model causes C_N^* in the model to increase by slightly less than that in the ST model. Accordingly, Y_N^* in the model jumps by less compared to the ST model. C_{NC}^* increases owing to rises in C_T^* and C_N^*, and thus despite the increased p_X^*, C_X^* rises thanks to the complementarity between C_{NC}^* and C_X^*. x^* falls because of a decrease in Y_F^*. Due to rises in C_X, C_X^* and x, foreign commodity output, Y_X^*, goes up. Overall, Y^* and C^* increase. However, rises in Y^* and C^* in the model are bigger than those in the ST model mainly due to increases in Y_X^* and C_X^* that are not in the ST model.



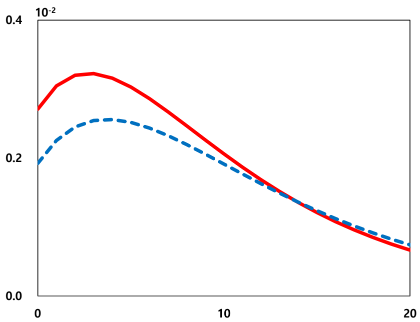
(a) H nontradable output



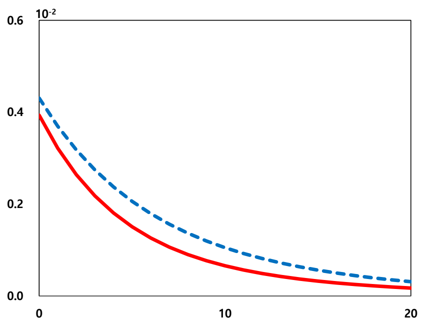
(b) H nontradable consumption



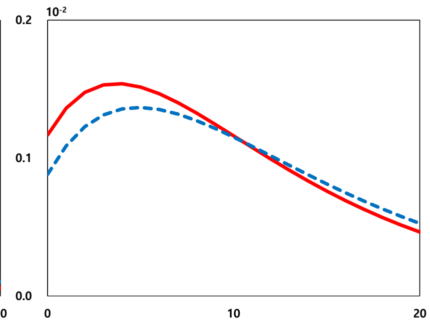
(c) H tradable output



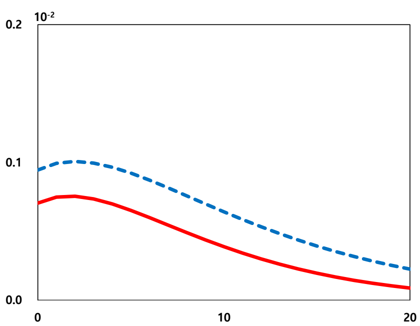
(d) H tradable consumption



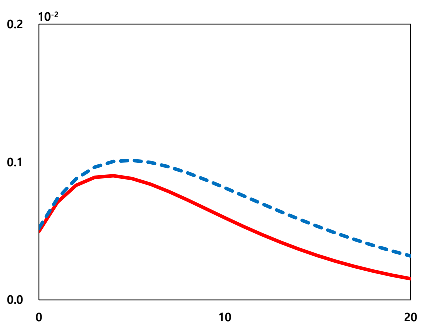
(e) H aggregate output



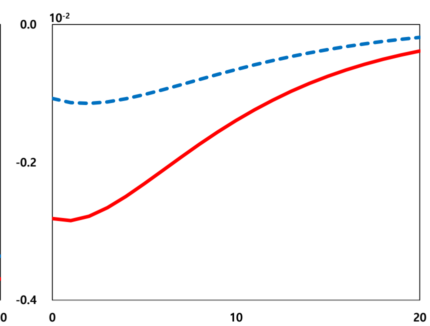
(f) H aggregate consumption



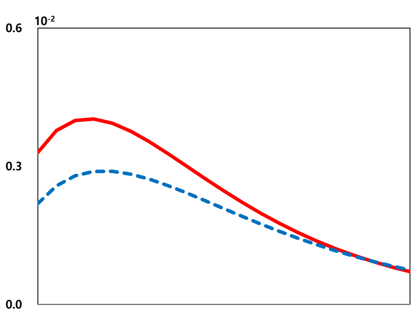
(g) F nontradable output



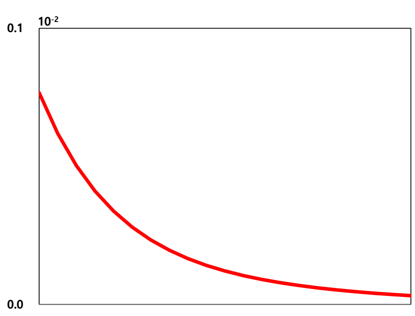
(h) F nontradable consumption



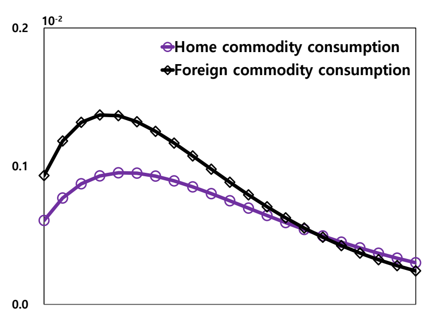
(i) F tradable output



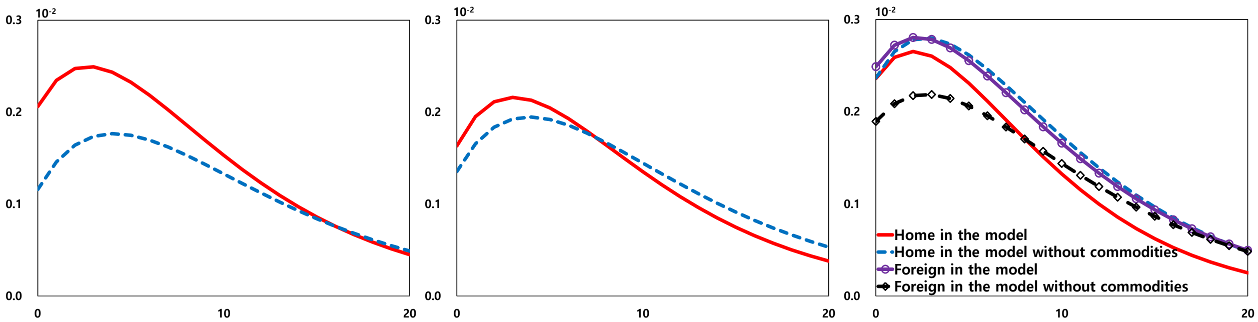
(j) F tradable consumption



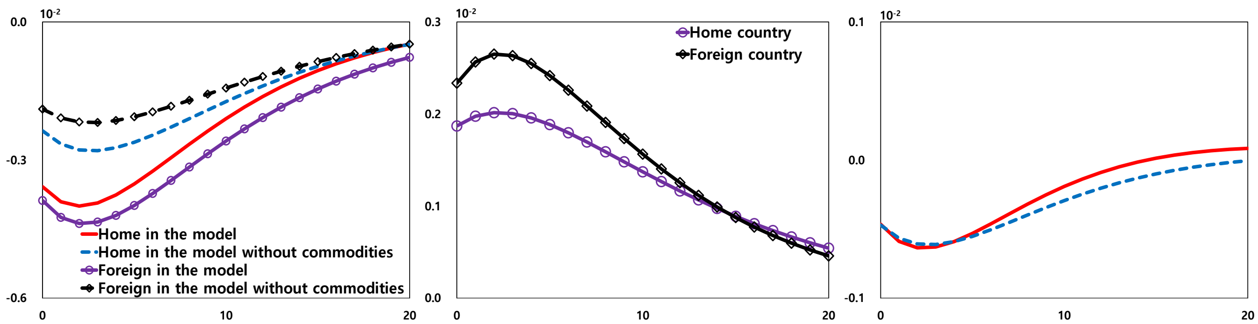
(k) F commodity output



(l) Commodity consumption



(m) F aggregate output (n) F aggregate consumption (o) Real prices of nontradables



(p) Real prices of tradables (q) Real commodity prices (r) Real exchange rates

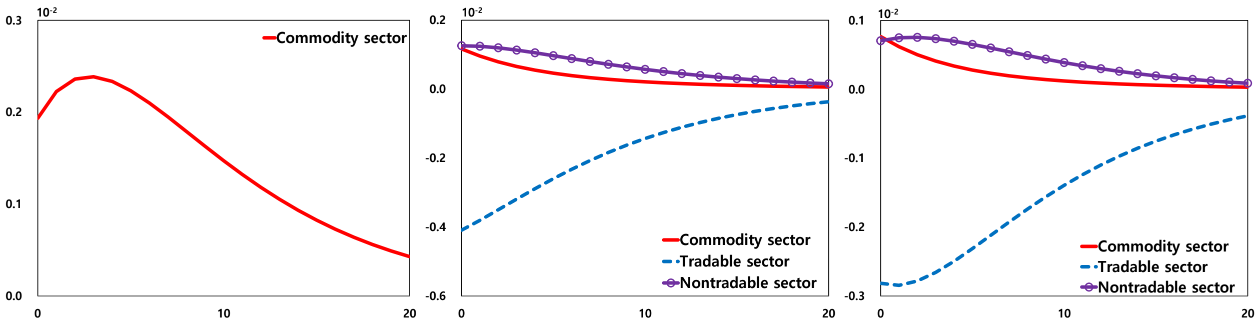
Figure 3: Responses to a positive productivity shock in the home tradable sector

Note: 'H' and 'F' mean the home and the foreign countries, respectively.

Application to the "Dutch disease"

The responses of the foreign country to the shock can be related to a typical example of the Dutch disease model of Corden and Neary (1982). According to them, a boom in the commodity sector can have effects on the economy in two ways: (i) the "resource movement effect" in which the boom in the commodity sector causes a rise in the marginal product of labour (the mobile factor) in the sector and thus draws labour, and (ii) the "spending effect" in which the increased real income resulting from the boom leads to an increase in consumption of nontradables. The spending effect results in an increase in prices of nontradable goods. Since prices of tradable goods are set by the world (they consider a small open economy), real exchange rates appreciate. Consequently, the boom leads to a rise in output in the nontradable sector but a fall in output in the tradable sector.

We can show all aspects of the Dutch disease in the responses of the foreign country in the model to the positive shock in the home tradable sector.



(a) F marginal product of labour (b) F labour in each sector (c) F output in each sector

Figure 4: Responses of the model to a positive productivity shock in the home tradable sector
Note: 'F' means the foreign country.

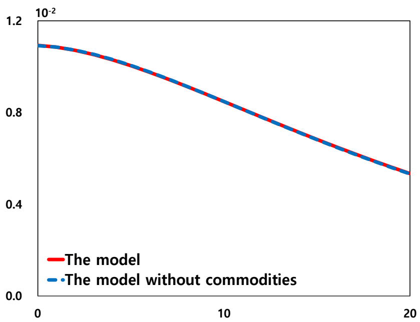
Figure 4 shows the responses of the foreign country in the model to a positive 1% productivity shock in the home tradable sector. The shock leads to an increase in home demand for commodities. Since the home country imports commodities from the foreign country, the shock results in a boom in the foreign commodity sector (see (c) in Figure 4). The boom leads to a rise in the marginal product of labour in the sector (see (a) in Figure 4), and thus the sector draws labour from other sectors. Labour in the sector jumps (see (b) in Figure 4). This explains the resource movement effect well. With regard to the spending effect, the boom triggered by the shock brings about a rise in consumption of nontradable goods in the foreign country (see (h) in Figure 3), which causes an increase in the real price of nontradable goods (see (o) in Figure 3). Accordingly, labour in the foreign nontradable sector rises. Since the foreign commodity and nontradable sectors draw labour, labour in the foreign tradable sector falls. Therefore, the boom causes a rise in output in the foreign nontradable sector and a fall in output in the foreign tradable sector.

4.3.2. A positive 1% productivity shock in the home nontradable sector

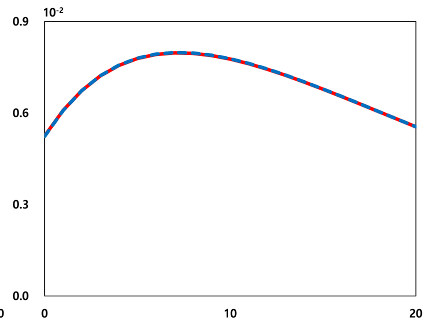
Figure 5 presents responses of the model and the ST model (the model without commodities) to a positive 1% productivity shock in the home nontradable sector. Since the responses of each sector in both models are very similar, I do not compare responses of each sector in the two models. Instead, I focus on comparing responses of aggregate variables in the two models.

With regard to the home country, in response to a positive productivity shock in the home nontradable sector, output, Y_N, and consumption, C_N, in the sector rise, and its real price, p_N, falls. Since an increase in Y_N puts upward pressure on the real prices of tradable goods produced in both countries and commodities in both countries, p_H, p_F, p^*_H, p^*_F, p_X and p^*_X, all rise. Thus, the real price of tradable goods in the home country, p_T, increases. Despite the increased p_T, home tradable consumption, C_T, rises thanks to the complementarity between C_N and C_T ($\eta_1 < 1$). Due to the rise in C_T, C_H and C_F increase. Because the nontradable sector draws labour thanks to the shock, labour in the tradable sector falls, which leads to a slight fall in output in the sector, Y_H. A fall in Y_H causes a decrease in commodity input for the production in the sector, x. Despite the increased p_X, commodity consumption in the home country, C_X, goes up owing the complementarity between C_{NC} and C_X. Consequently, home aggregate output and consumption, Y and C, jump in response to the shock, but the increase in Y in the model is slightly lower than that in the ST model because of the slightly bigger fall in Y_H in the model than that in the ST model. C in both models increase by almost the same degree.

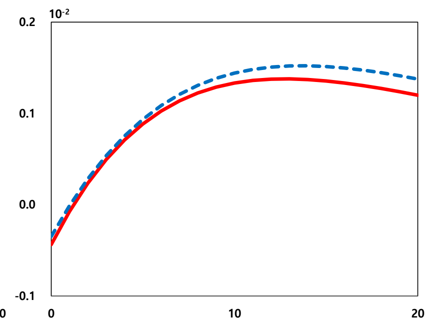
Now, consider the foreign country. Rises in p^*_F and p^*_H, and therefore p^*_T cause decreases in C^*_H and C^*_F and thus C^*_T. A rise in p^*_T brings about a fall in p^*_N. Although p^*_N falls, C^*_N decreases due to the complementarity between C^*_T and C^*_N. Due to falls in C^*_T and C^*_N, C^*_{NC} decreases. Owing to the complementarity between C^*_X and C^*_{NC} and a rise in p^*_X, C^*_X also falls. Thanks to the increased C_F, demand for capital in the foreign tradable sector increases, which brings about a rise in its investment, I^*_T. Therefore, output in the foreign tradable sector, Y^*_F, goes up, which leads to an increase in x^*. Increases in C_X and x^* cause a jump in output in the foreign commodity sector, Y^*_X. A fall in C^*_N brings about a decrease in Y^*_N. As a result, Y^* increases, but C^* falls. Owing to a rise in Y^*_X that is not in the ST model, Y^* in the model increases by more than that in the ST model does, and due to a fall in C^*_X which is not in the ST model, C^* in the model decreases by more than that in the ST model.



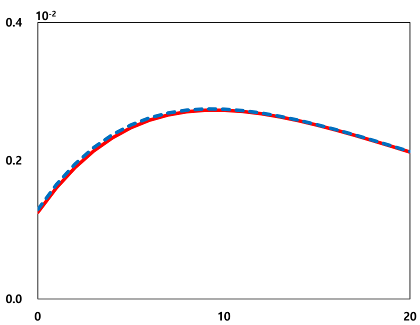
(a) H nontradable output



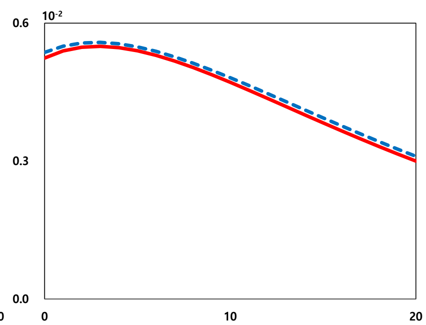
(b) H nontradable consumption



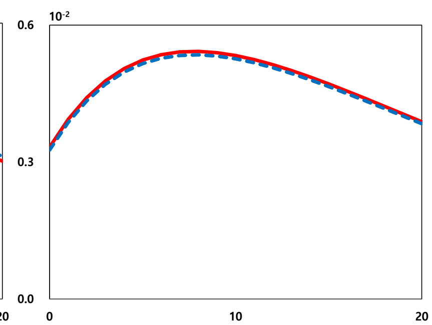
(c) H tradable output



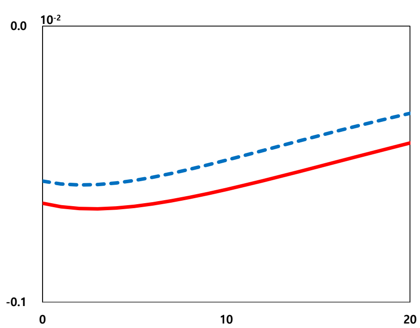
(d) H tradable consumption



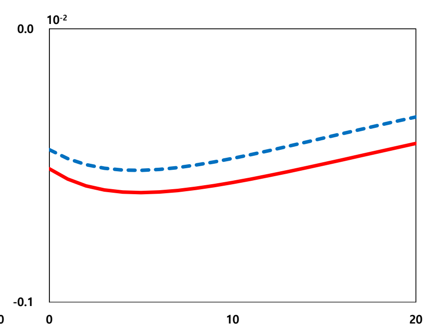
(e) H aggregate output



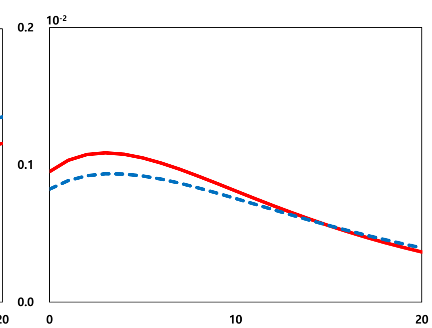
(f) H aggregate consumption



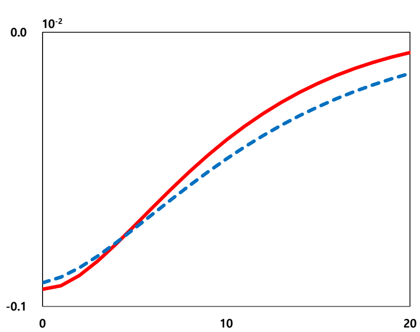
(g) F nontradable output



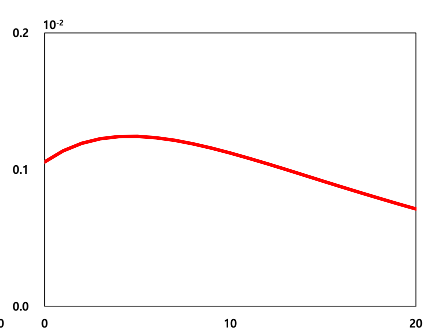
(h) F nontradable consumption



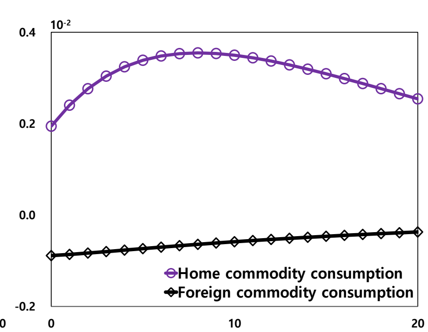
(i) F tradable output



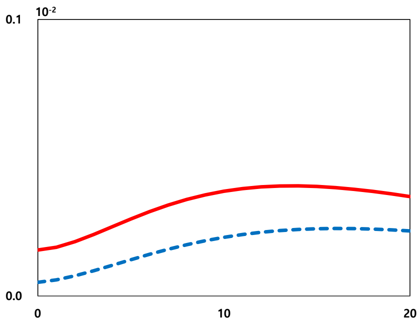
(j) F tradable consumption



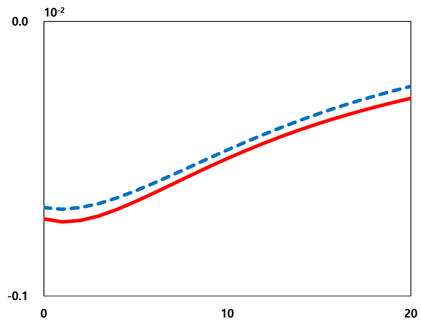
(k) F commodity output



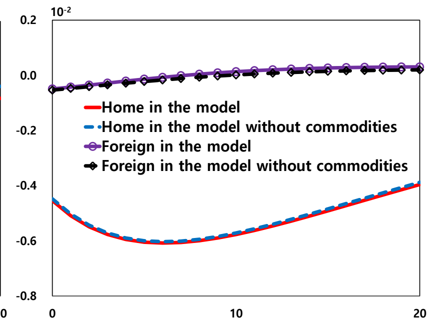
(l) Commodity consumption



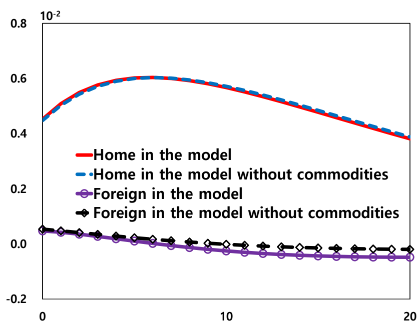
(m) F aggregate output



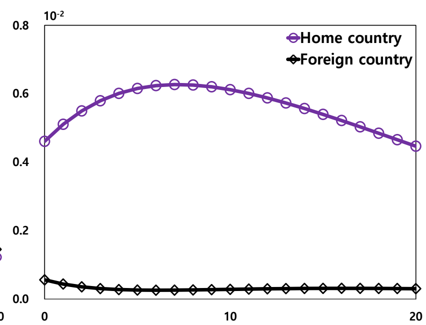
(n) F aggregate consumption



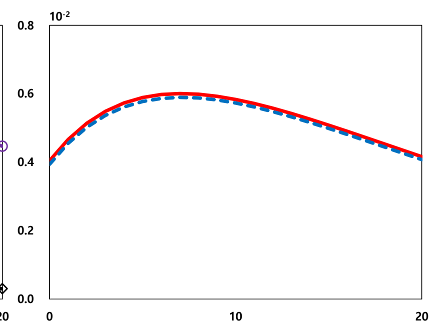
(o) Real prices of nontradables



(p) Real prices of tradables



(q) Real commodity prices



(r) Real exchange rates

Figure 5: Responses to a positive productivity shock in the home nontradable sector

Note: 'H' and 'F' mean the home and the foreign countries, respectively.

4.4. Sensitivity analysis

In the model, the parameters for the elasticity of substitution between commodity and non-commodity consumption goods (η_0), the weight of commodity consumption goods in the composite consumption goods (γ_0), and the elasticity of substitution between commodities and capital in the production of tradable goods (ν) are new parameters due to the introduction of commodities compared to the ST model.[26] Thus, whether the main results of the model (higher output correlation than the consumption correlation and the output correlation in the ST model) are sensitive to changes in the values of these three parameters needs to be assessed. To do so, I set reasonable ranges of the parameter values. Specifically, $\eta_0 \in [0, 1]$ which is based on previous studies. $\gamma_0 \in [0.1, 0.13]$ which matches the minimum

[26] In fact, the parameter related to the weight of commodities in the production of tradable goods (a) is also new one. However, since the discount factor (β), the depreciation rate (δ), the steady state ratio of capital to commodities in the tradable production (K_T/x) and ν determine its value, the assessment of the sensitivity to changes in its value is not conducted.

and maximum values in the NIPA data for 1990-2015. I set a range of $\nu \in [0.5, 1]$ again based on previous studies. Figure 6 shows the output and consumption correlations between the two countries according to changes in the values of these three parameters.

Elasticity of substitution between commodity and noncommodity goods (η_0)

(a) in Figure 6 shows the output and consumption correlations between the two countries according to changes in the elasticity of substitution between commodity and noncommodity consumption goods (η_0).

As already shown, a rise in the output correlation and a fall in the consumption correlation are due to the complementarity between commodity and noncommodity consumption goods. A rise in η_0 means weaker complementarity. Hence, we would expect that a rise in η_0 will decrease the output correlation and increase the consumption correlation, holding other factors constant. However, since η_0 is directly related to commodity prices from equation (7), changes in it affect the responses of real commodity prices to the productivity shocks, which also have impacts on the output and consumption correlations. Consequently, as η_0 rises, changes in the output correlation are not noticeable, but the consumption correlation increases. Nevertheless, as can be seen in (a) in Figure 6, the fluctuations are small, and thus as long as η_0 is in reasonable ranges, the main results of this chapter hold.

Weight of commodity goods in the composite consumption goods (γ_0)

Now consider the changes in the weight of commodity consumption goods in the composite consumption goods (γ_0). (b) in Figure 6 presents the output and consumption correlations in the model according to the various values of γ_0.

Conversely to η_0 in which commodity consumption is decreasing, commodity consumption is increasing in γ_0. This can be seen in the households' optimal commodity consumption allocation, $C_{X,t} = \gamma_0 p_{X,t}^{-\eta_0} C_t$. Thus, an increase in γ_0 and a fall in η_0 have very similar effects on the output and consumption correlations, i.e. we would expect that a rise in γ_0 will increase the output correlation and decrease the consumption correlation, holding other factors constant. Although like η_0, γ_0 is directly related to commodity prices from equation

(7), the impact of changes in γ_0 on real commodity prices is much weaker than η_0. As a result, consistently with the expectation, as γ_0 increases, the output correlation goes up and the consumption correlation falls. Overall, the output correlation is always higher than that in the ST model and the consumption correlation in the model as long as γ_0 is in a reasonable interval.

In addition, since according to the U.S. Energy Information Administration (EIA) the U.S. could become a net energy-exporting country by 2026, meaning that the U.S. is likely to be a minor commodity-importing country rather than a commodity-exporting country,[27] whether the main results of the model change in the case in which the home country imports commodities to a much lesser extent needs to be assessed. Because the lower γ_0, the smaller the home country's imports of commodities from the foreign country, this can be assessed by reducing γ_0 greatly. Specifically, I consider two cases; 33% and 50% falls in γ_0 (γ_0=0.075, 0.056). When γ_0 falls by 33% (γ_0=0.075), the model generates higher output correlation (0.772) than consumption correlation (0.759). γ_0=0.056 causes almost equal output and consumption correlations (0.765 for the output correlation and 0.769 for the consumption correlation). In sum, if the home country shifts from a major commodity-importing country to a minor commodity-importing country, the output correlation in the model is higher than that in the ST model (0.658) and the consumption correlation in the model is smaller than that in the ST model (0.774). In other words, the model yields closer international business cycle statistics to the data than the ST model, regardless of whether the home country is a major or a minor commodity-importing country.

Elasticity of substitution between commodities and capital in production (ν)

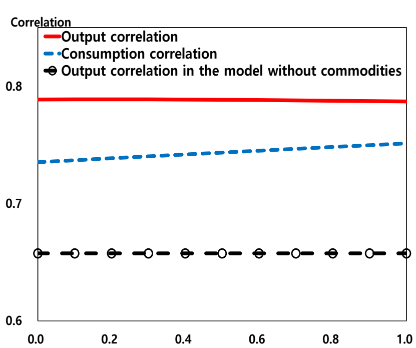
As the elasticity of substitution between commodities and capital in the production of tradable goods (ν) goes up, both output and consumption correlations fall slowly (see (c) in Figure 6).

[27] According to the EIA's Annual Energy Outlook 2017, the EIA expects that the U.S. could become a net energy-exporting country by 2026. Since the U.S. is a net importing country of other commodities such as basic metal and wood, even if the U.S. becomes a net energy-exporting country, it will not become a net commodity-exporting country. Rather, the U.S. is likely to shift from a major commodity-importing country to a minor commodity-importing country.

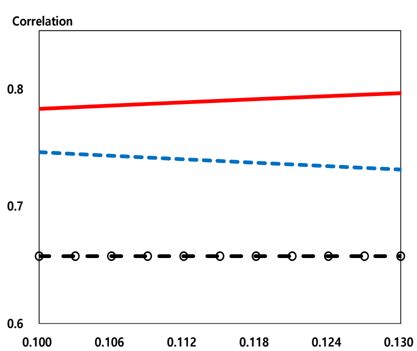
As for the output correlation, when ν is high, it is easier for commodity input to be substituted by capital input, which means weaker complementarity between the two. Furthermore, ν is not directly related to commodity prices. Therefore, when ν is high, the increased home demand for imports of commodities for the tradable production in response to positive productivity shocks is offset by the increased real commodity prices by more than when ν is small. This leads foreign commodity output to rise by less, which brings about a smaller increase in foreign aggregate output, i.e. the larger ν is, the smaller the positive spillover to the foreign country from positive productivity shocks. Therefore, the output correlation decreases slowly as ν becomes greater.

With regard to the consumption correlation, ν is not directly related to commodity consumption, and changes in commodity consumption in response to productivity shocks in the nontradable sector decrease the consumption correlation. Therefore, although ν increases, changes in commodity consumption is very marginal. Nevertheless, when ν is high, foreign noncommodity consumption goes up by less due to a smaller rise in its aggregate output compared to the case of low ν, which leads to a fall in the consumption correlation. Consequently, high ν results in less positively correlated consumptions of the two countries.

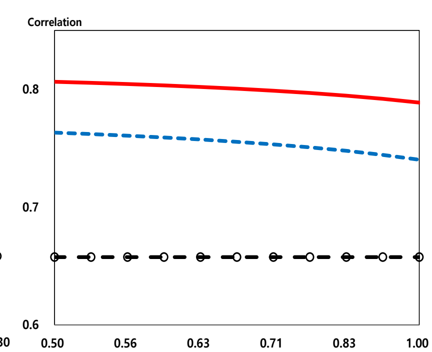
Overall, the output correlation is higher than that in the ST model and the consumption correlation in the model when ν is in a reasonable interval.



(a) η_0



(b) γ_0



(c) ν

Figure 6: Sensitivity analysis

5. Conclusion

In this chapter, I set up a two-country model with commodities and idiosynctratic commodity trade structures of countries to analyse international business cycles between the U.S. and commodity-exporting countries. Consistently with the empirical finding, the output correlation in the model is higher than that in a standard international business cycle model (the ST model). The complementarity between commodity and noncommodity consumption goods enables productivity shocks to have stronger spillovers to the other country. Moreover, the consumption correlation in the model becomes smaller than that in the ST model, since commodity consumptions in both countries, which are not present in the ST model, are less correlated compared to noncommodity consumptions. As a result, the model generates output correlation that is greater than the consumption correlation unlike standard models, and thus mitigates the consumption correlation puzzle. The model also explains the typical Dutch disease by showing that a boom in the commodity sector leads to a rise in output in the nontradable sector and a fall in output in the tradable sector. Finally, the sensitivity analysis of the model's results with regards to the parameters in the newly introduced features, as compared to the ST model, show that the main results of this chapter hold as long as the parameter values are in reasonable ranges.

Adding commodities to open economy macro models with consideration for different commodity trade structures of countries therefore appears to be useful, since it helps to explain key features of international business cycle correlations between the U.S. and commodity-exporting countries. The framework that this chapter proposes is therefore promising for further research on the international macroeconomic interactions between the U.S. and commodity-exporting countries, especially the international transmissions of monetary and fiscal policies.

References

Alquist, R. and O. Gervais (2013). The role of financial speculation in driving the price of crude oil. *Energy Journal 34*, 35–54.

Arora, V. and P. Gomis-Porqueras (2011). Oil price dynamics in a real business cycle model. CAMA Working Paper 17/2011, Australian National University.

Backus, D., P. Kehoe, and F. Kydland (1992). International real business cycles. *Journal of Political Economy 101*, 745–775.

Backus, D., P. Kehoe, and F. Kydland (1995). International business cycles: Theory and evidence. *Frontiers of Business Cycle Research (Princeton: Princeton University Press)*, 331–356.

Backus, D. K. and M. J. Crucini (2000). Oil prices and the terms of trade. *Journal of International Economics 50*, 185–213.

Blanchard, O. J. and J. Galí (2007). The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? NBER Working Paper No. 13368.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2008). Optimal monetary policy with distinct core and headline inflation rates. *Journal of Monetary Economics 55*, 18–33.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2011). Oil shocks and external adjustment. *Journal of International Economics 83*, 168–184.

Cooper, J. (2003). Price elasticity of demand for crude oil: Estimates for 23 countries. *OPEC Review 27*, 1–8.

Corden, W. and J. Neary (1982). Booming sector and deindustrialisation in a small open economy. *Economic Journal 92*, 825–848.

Corsetti, G., L. Dedola, and S. Leduc (2008). International risk sharing and the transmission of productivity shocks. *Review of Economic Studies 75*, 443–473.

Faia, E. (2007). Finance and international business cycles. *Journal of Monetary Economics 54*, 1018–1034.

Fattouh, B., L. Kilian, and L. Mahadeva (2013). The role of speculation in oil markets: What have we learned so far? *Energy Journal 34*, 7–33.

Galí, J. and T. Monacelli (2005). Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies 72*, 707–734.

Huynh, B. T. (2016). Macroeconomic effects of energy price shocks on the business cycle. *Macroeconomic Dynamics 20*, 623–642.

Kehoe, P. and F. Perri (2002). International business cycles and endogenous incomplete markets. *Econometrica 70*, 907–928.

Kilian, L. and T. K. Lee (2014). Quantifying the speculative component in the real price of oil: The role of global oil inventories. *Journal of International Money and Finance 41*, 71–87.

Kilian, L. and D. P. Murphy (2014). The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics 29*, 454–478.

Kim, I. and P. Loungani (1992). The role of energy in real business cycle models. *Journal of Monetary Economics 29*, 173–189.

Knittel, C. R. and R. S. Pindyck (2016). The simple economics of commodity price speculation. *American Economic Journal: Macroeconomics 8*, 85–110.

Moutos, T. and D. Vines (1989). The simple macroeconomics of North-South interaction. *American Economic Review Papers and Proceedings 79*, 270–276.

Natal, J.-m. (2012). Monetary policy response to oil price shocks. *Journal of Money, Credit and Banking 44*, 53–101.

Smith, J. L. (2009). World oil: Market or mayhem. *Journal of Economic Perspectives 23*, 145–164.

Stockman, A. C. and L. L. Tesar (1995). Tastes and technology in a two-country model of the business cycle: Explaining international comovements. *American Economic Review 85*, 168–185.

Ueda, K. (2012). Banking globalization and international business cycles: Cross-border chained credit contracts and financial accelerators. *Journal of International Economics 86*, 1–16.

Zimmermann, C. (1997). International real business cycles among heterogeneous countries. *European Economic Review 41*, 319–355.

Appendix

A. Inventories, demand for commodities and commodity prices

In this section, I investigate how inventories of commodities change in response to a rise in demand for commodities triggered by a positive productivity shock, and whether changes in inventories of commodities affect commodity prices by using the model of Knittel and Pindyck (2016).

Let N_t be the commodity inventory level. Then, the change in inventories of commodities is

$$\triangle N_t = X(P_{X,t}; z_{2,t}, \varepsilon_{2,t}) - D(P_{X,t}; z_{1,t}, \varepsilon_{1,t}) \tag{16}$$

where D is demand for commodities, and X is supply of commodities. z_1 and z_2 denote demand-shifting and supply-shifting variables, respectively, and ε_1 and ε_2 are random shocks.

Then, the inverse net demand function can be written as

$$P_{X,t} = f(\triangle N_t; z_{1,t}, z_{2,t}, \varepsilon_{1,t}, \varepsilon_{2,t}) \tag{17}$$

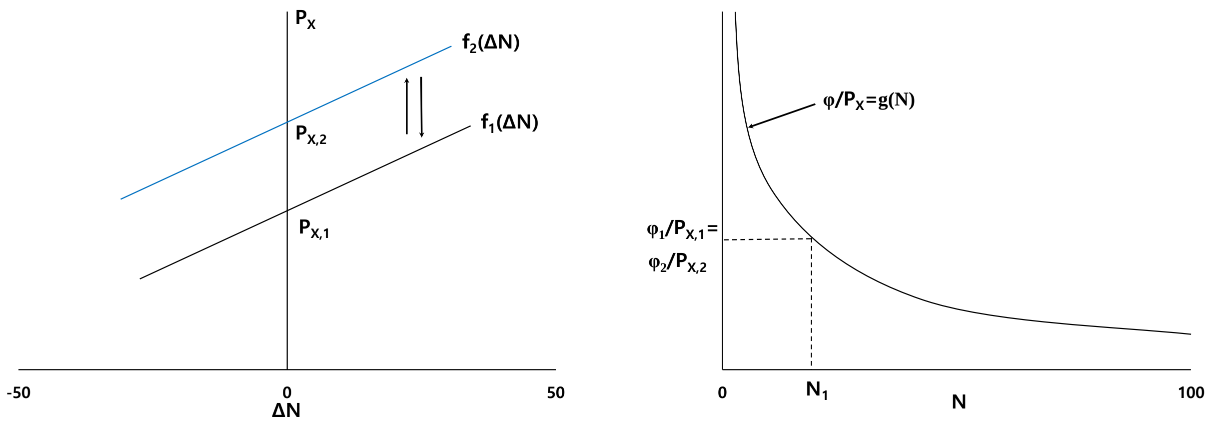
Denote ψ_t and $N(\psi)$ the marginal value of inventories and the demand for inventories respectively. Since ψ_t is small when the inventory level is large and vice versa, $N'(\psi) < 0$ and $N''(\psi) > 0$. The inverse demand for inventories is

$$\psi_t / P_{X,t} = g(N_t; z_{3,t}, \varepsilon_{3,t}) \tag{18}$$

where z_3 is demand-shifting variables such as the volatility of price and the expected changes in demand for commodities, and ε_3 is a random shock. As one may expect, ψ is proportional to P_X, which is assumed by Knittel and Pindyck (2016) and confirmed by statistical studies. Hence, ψ / P_X is independent of P_X.

Figure 7 illustrates the effect of a unexpected temporary rise in demand for commodities. The net demand for commodities curve on the left-hand side of Figure 7 moves upward and P_X increases from $P_{X,1}$ to $P_{X,2}$. The demand for inventories curve on the right-hand side of

Figure 7 does not move, and ψ/P_X remains at the same level. Then, when the net demand for commodities curve returns to the initial state, P_X also returns to $P_{X,1}$. Therefore, inventories of commodities do not change.

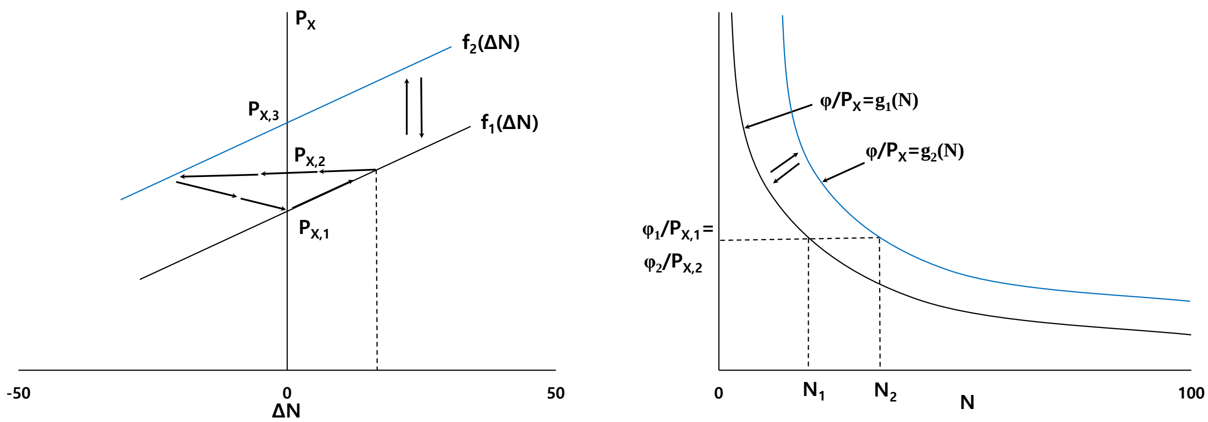


(a) Net demand for commodities

(b) Demand for inventories of commodities

Figure 7: Unexpected temporary increase in demand for commodities

However, if the temporary rise in demand for commodities is anticipated (for example, a seasonal increase in the demand for oil), the result is different. Figure 8 shows the impact of an expected rise in demand for commodities. Since the increase in demand for commodities is anticipated, the demand for inventories curve on the right-hand side of Figure 8 shifts upward ahead of the rise in demand for commodities. The inventory level increases from N_1 to N_2, and from the net demand for commodities curve on the left-hand side of Figure 8, P_X increases from $P_{X,1}$ to $P_{X,2}$. When the net demand for commodities curve shifts upward, the demand for inventories curve returns to the initial state since the demand for commodities is anticipated to fall. Thus, the inventory level decreases and returns to the initial level, N_1. P_X remains $P_{X,2}$ rather than $P_{X,3}$. Then, when the net demand curve returns to the initial state, P_X also returns to the initial level, $P_{X,1}$. Consequently, the inventory level increases and then falls.



(a) Net demand for commodities (b) Demand for inventories of commodities

Figure 8: Expected temporary increase in demand for commodities

Knittel and Pindyck (2016) assume that the functional form of demand for commodities is $D = k_D P_X^{\eta_D}$ and that of supply of commodities is $X = k_s P_X^{\eta_s}$. Then, the change in inventories of commodities is

$$\triangle N_t = k_s P_{X,t}^{\eta_s} - k_D P_{X,t}^{\eta_D} \tag{19}$$

where k_S and k_D are parameters that include market fundamentals shifting supply and demand. η_S and η_D are the supply and demand elasticities, respectively.

Divide equation (19) by D_t:

$$\frac{\triangle N_t}{D_t} = \frac{X_t}{D_t} - 1 = \frac{k_S}{k_D} P_{X,t}^{\eta_s - \eta_D} - 1 \tag{20}$$

Take logs and then first differences of equation (20):

$$\triangle \ln P_{X,t} = \frac{1}{\eta_S - \eta_D} \left(\triangle \ln k_D - \triangle \ln k_S\right) + \frac{1}{\eta_S - \eta_D} \left(\triangle \ln X_t / D_t\right) \tag{21}$$

Since any change in market fundamentals related to supply and demand is reflected in k_S and k_D, the inventory component of commodity price changes is

$$\triangle \ln P_{X,t}^{I} = \frac{1}{\eta_S - \eta_D} \left(\triangle \ln X_t / D_t\right) \tag{22}$$

Knittel and Pindyck (2016) estimate $\triangle \ln P^I_{X,t}$ by using data for oils from January 1998 to June 2012. They consider two cases for the values of $\eta_S - \eta_D$: $\eta_S - \eta_D = 0.2$ ($\eta_S = 0.1$ and $\eta_D = -0.1$) and $\eta_S - \eta_D = 0.1$ ($\eta_S = 0.05$ and $\eta_D = -0.05$). They find that the cumulative effect from changes in inventories of oils on the cumulative changes in the log of oil prices fluctuates around zero. In other words, changes in inventories of commodities do not significantly affect commodity prices.

According to the model of Knittel and Pindyck (2016), omitting inventories of commodities in the model in this chapter may not matter greatly. Specifically, since productivity shocks in this chapter are temporary unexpected shocks, changes in demand for commodities due to the shocks are also temporary and unexpected. Thus, inventories of commodities do not change in response to the shocks. This means that even if there are inventories of commodities in the model and the U.S. can use inventories to meet the increased demand for commodities triggered by a positive productivity shock to the U.S., the U.S. will import the same amount of commodities as the model without inventories. This is because if the U.S. uses inventories to meet the increased demand for commodities, inventories will reduce. Since inventories do not change in response to unexpected changes in demand for commodities, the U.S. will import commodities to maintain the inventory level. Consequently, the existence of inventories of commodities does not make a difference to the results.

Even if, contrary to the model of Knittel and Pindyck (2016), inventories change in response to unexpected changes in demand for commodities, the positive effects of a positive productivity shock to the U.S. on commodity-exporting countries will be only slightly weaker compared to the case without inventories. Specifically, in this case the U.S. inventory level will reduce in response to the shock. However, commodity prices will rise thanks to the increased demand, which is confirmed by not only Knittel and Pindyck (2016) but also many recent studies (for example Smith, 2009; Fattouh, Kilian and Mahadeva, 2013; Alquist and Gervais, 2013; Kilian and Murphy, 2014; Kilian and Lee, 2014; etc.) concluding that oil inventory changes have no significant effects on oil prices. Therefore, since the U.S. will import less commodities in the model with inventories of commodities, productivity shocks to the U.S. will have slightly weaker spillovers to commodity-exporting countries.

B. Data sources

This section describes the data used in this chapter. The data is mainly from two sources: OECD and IMF.

Figures 1, 2 and table 1 The 60 countries are those whose data of commodity exports and imports are available in the OECD Trade in Value Added.

Annual real GDPs for computing GDP correlations are taken from the IMF World Economic Outlook, since annual real GDP data of some countries such as Argentina and Bulgaria among the 60 countries are not available in the OECD National Accounts. Net commodity exports are the gross exports minus imports of agriculture, hunting, forestry, fishing, mining, quarrying, wood and basic metal industries in the OECD Trade in Value Added, and nominal GDP is drawn from the IMF World Economic Outlook. The ratio of net commodity exports to GDP is average of dividing net commodity exports by nomial GDP for the period 1995-2011. The banks' return on assets are taken from Federal Reserve Economic Data. The financial distance is average of differences between banks' retrun on asset in the U.S. and that in other countries for the period 1996-2014. The ratio of trade with the U.S. to GDP is average of dividing exports to the U.S. plus imports from the U.S. by nominal GDP for the period 1996-2011.

Tables 2 and 4 Annual real GDP, real private consumption and real private fixed investment of OECD countries are taken from OECD National Accounts. Since the pre 1990 data for most Eastern European countries are not available, the data cover the period 1990-2015 with the exception of Estonia which covers 1993-2015, Hungary which covers 1991-2015, Latvia which covers 1994-2015, and Slovak Republic which covers 1992-2015.

For the trade-weighted average, the average trade weight of an OECD country i for the period 1995-2011 is constructed by summing exports from an OECD country i to the U.S. and imports from the U.S. to the OECD country i, and dividing by the total OECD countries' trade with the U.S . The trade data is drawn from OECD Trade in Value Added.

Commodity-exporting OECD countries are Australia, Canada, Chile, Estonia, Finland, Iceland, Latvia, Luxembourg, Mexico, the Netherlands, New Zealand and Norway whose ratios of net commodity exports to GDP are positive.

C. Equilibrium conditions of the model

In this section, I present the equilibrium system of the model described in Section 3.

- Home households' intertemporal problem:

$$1 = \beta \mathbb{E}_t \left[\frac{C_t}{C_{t+1}} R_t \right] \tag{23}$$

$$W_{T,t} = L_t^{\chi} C_t \tag{24}$$

$$W_{N,t} = L_t^{\chi} C_t \tag{25}$$

$$C_t = \vartheta e_t C_t^* \tag{26}$$

with $R_t = \{(1-\delta)p_{H,t+1} + r_{T,t+1}\}/p_{H,t} = \{(1-\delta)p_{N,t+1} + r_{N,t+1}\}/p_{N,t}$ and $L_t = L_{T,t} + L_{N,t}$

- Foreign households' intertemporal problem:

$$1 = \beta \mathbb{E}_t \left[\frac{C_t^*}{C_{t+1}^*} R_t^* \right] \tag{27}$$

$$W_{T,t}^* = L_t^{*\chi} C_t^* \tag{28}$$

$$W_{N,t}^* = L_t^{*\chi} C_t^* \tag{29}$$

$$W_{X,t}^* = L_t^{*\chi} C_t^* \tag{30}$$

with $R_t^* = \{(1-\delta)p_{F,t+1}^* + r_{T,t+1}^*\}/p_{F,t}^* = \{(1-\delta)p_{N,t+1}^* + r_{N,t+1}^*\}/p_{N,t}^* = \{(1-\delta)p_{X,t+1}^* + r_{X,t+1}^*\}/p_{X,t}^*$ and $L_t^* = L_{T,t}^* + L_{N,t}^* + L_{X,t}^*$

- Home households' consumption allocation:

$$C_{NC,t} = (1-\gamma_0) p_{NC,t}^{-\eta_0} C_t \tag{31}$$

$$C_{X,t} = \gamma_0 p_{X,t}^{-\eta_0} C_t \tag{32}$$

$$C_{T,t} = (1-\gamma_1)\left(\frac{p_{T,t}}{p_{NC,t}}\right)^{-\eta_1} C_{NC,t} \tag{33}$$

$$C_{N,t} = \gamma_1 \left(\frac{p_{N,t}}{p_{NC,t}}\right)^{-\eta_1} C_{NC,t} \tag{34}$$

$$C_{H,t} = (1-\gamma_2)\left(\frac{p_{H,t}}{p_{T,t}}\right)^{-\eta_2} C_{T,t} \tag{35}$$

$$C_{F,t} = \gamma_2 \left(\frac{p_{F,t}}{p_{T,t}}\right)^{-\eta_2} C_{T,t} \tag{36}$$

- Foreign households' consumption allocation:

$$C^*_{NC,t} = (1-\gamma_0) p^{*-\eta_0}_{NC,t} C^*_t \tag{37}$$

$$C^*_{X,t} = \gamma_0 p^{*-\eta_0}_{X,t} C^*_t \tag{38}$$

$$C^*_{T,t} = (1-\gamma_1)\left(\frac{p^*_{T,t}}{p^*_{NC,t}}\right)^{-\eta_1} C^*_{NC,t} \tag{39}$$

$$C^*_{N,t} = \gamma_1 \left(\frac{p^*_{N,t}}{p^*_{NC,t}}\right)^{-\eta_1} C^*_{NC,t} \tag{40}$$

$$C^*_{F,t} = (1-\gamma^*_2)\left(\frac{p^*_{F,t}}{p^*_{T,t}}\right)^{-\eta_2} C^*_{T,t} \tag{41}$$

$$C^*_{H,t} = \gamma^*_2 \left(\frac{p^*_{H,t}}{p^*_{T,t}}\right)^{-\eta_2} C^*_{T,t} \tag{42}$$

- Home price indices:

$$1 = (1-\gamma_0) p_{NC,t}^{1-\eta_0} + \gamma_0 p_{X,t}^{1-\eta_0} \tag{43}$$

$$p_{NC,t}^{1-\eta_1} = (1-\gamma_1) p_{T,t}^{1-\eta_1} + \gamma_1 p_{N,t}^{1-\eta_1} \tag{44}$$

$$p_{T,t}^{1-\eta_2} = (1-\gamma_2) p_{H,t}^{1-\eta_2} + \gamma_2 p_{F,t}^{1-\eta_2} \tag{45}$$

- Foreign price indices:

$$1 = (1-\gamma_0) p^{*\,1-\eta_0}_{NC,t} + \gamma_0 p^{*\,1-\eta_0}_{X,t} \tag{46}$$

$$p^{*1-\eta_1}_{NC,t} = (1-\gamma_1)p^{*1-\eta_1}_{T,t} + \gamma_1 p^{*1-\eta_1}_{N,t} \tag{47}$$

$$p^{*1-\eta_2}_{T,t} = (1-\gamma_2^*)p^{*1-\eta_2}_{F,t} + \gamma_2^* p^{*1-\eta_2}_{H,t} \tag{48}$$

- Laws of one price:

$$p_{H,t} = e_t p^*_{H,t} \tag{49}$$

$$p_{F,t} = e_t p^*_{F,t} \tag{50}$$

$$p_{X,t} = e_t p^*_{X,t} \tag{51}$$

- Home nontradable good producers' optimality conditions:

$$Y_{N,t} = A_{N,t} K^{\alpha_N}_{N,t} L^{1-\alpha_N}_{N,t} \tag{52}$$

$$W_{N,t} = (1-\alpha_N) p_{N,t} \frac{Y_{N,t}}{L_{N,t}} \tag{53}$$

$$R_{t-1} = \frac{1}{p_{N,t-1}} \{(1-\delta)p_{N,t} + \alpha_N p_{N,t} \frac{Y_{N,t}}{K_{N,t}}\} \tag{54}$$

- Foreign nontradable good producers' optimality conditions:

$$Y^*_{N,t} = A^*_{N,t} K^{*\alpha_N}_{N,t} L^{*1-\alpha_N}_{N,t} \tag{55}$$

$$W^*_{N,t} = (1-\alpha_N) p^*_{N,t} \frac{Y^*_{N,t}}{L^*_{N,t}} \tag{56}$$

$$R^*_{t-1} = \frac{1}{p^*_{N,t-1}} \{(1-\delta)p^*_{N,t} + \alpha_N p^*_{N,t} \frac{Y^*_{N,t}}{K^*_{N,t}}\} \tag{57}$$

- Home tradable good producers' optimality conditions:

$$Y_{H,t} = A_{T,t} \{(1-a) K^{\frac{\nu-1}{\nu}}_{T,t} + a x_t^{\frac{\nu-1}{\nu}}\}^{\frac{\nu\alpha}{\nu-1}} L^{1-\alpha}_{T,t} \tag{58}$$

$$W_{T,t} = (1-\alpha) p_{H,t} \frac{Y_{H,t}}{L_{T,t}} \tag{59}$$

$$R_{t-1} = \frac{1}{p_{H,t-1}} \{(1-\delta)p_{H,t} + \alpha(1-a) p_{H,t} K^{-\frac{1}{\nu}}_{T,t} \frac{Y_{H,t}}{(1-a)K^{\frac{\nu-1}{\nu}}_{T,t} + a x_t^{\frac{\nu-1}{\nu}}}\} \tag{60}$$

$$p_{X,t} = a\alpha p_{H,t} x_t^{-\frac{1}{\nu}} \frac{Y_{H,t}}{(1-a)K^{\frac{\nu-1}{\nu}}_{T,t} + a x_t^{\frac{\nu-1}{\nu}}} \tag{61}$$

- Foreign tradable good producers' optimality conditions:

$$Y^*_{F,t} = A^*_{T,t}\{(1-a)K^{*\frac{\nu-1}{\nu}}_{T,t} + a x^{*\frac{\nu-1}{\nu}}_{t}\}^{\frac{\nu\alpha}{\nu-1}} L^{*1-\alpha}_{T,t} \tag{62}$$

$$W^*_{T,t} = (1-\alpha)p^*_{F,t}\frac{Y^*_{H,t}}{L^*_{T,t}} \tag{63}$$

$$R^*_{t-1} = \frac{1}{p^*_{F,t-1}}\{(1-\delta)p^*_{F,t} + \alpha(1-a)p^*_{F,t}K^{*-\frac{1}{\nu}}_{T,t}\frac{Y^*_{F,t}}{(1-a)K^{*\frac{\nu-1}{\nu}}_{T,t} + a x^{*\frac{\nu-1}{\nu}}_{t}}\} \tag{64}$$

$$p^*_{X,t} = a\alpha p^*_{F,t}x^{*-\frac{1}{\nu}}_{t}\frac{Y^*_{F,t}}{(1-a)K^{*\frac{\nu-1}{\nu}}_{T,t} + a x^{*\frac{\nu-1}{\nu}}_{t}} \tag{65}$$

- Foreign commodity producers' optimality conditions:

$$Y^*_{X,t} = A^*_X K^{*\alpha_X}_{X,t} L^{*1-\alpha_X}_{X,t} \tag{66}$$

$$W^*_{X,t} = (1-\alpha_X)p^*_{X,t}\frac{Y^*_{X,t}}{L^*_{X,t}} \tag{67}$$

$$R^*_{t-1} = \frac{1}{p^*_{X,t-1}}\{(1-\delta)p^*_{X,t} + \alpha_X p^*_{X,t}\frac{Y^*_{X,t}}{K^*_{X,t}}\} \tag{68}$$

- Laws of motion for capital:

$$K_{N,t+1} = (1-\delta)K_{N,t} + I_{N,t} \tag{69}$$

$$K^*_{N,t+1} = (1-\delta)K^*_{N,t} + I^*_{N,t} \tag{70}$$

$$K_{T,t+1} = (1-\delta)K_{T,t} + I_{T,t} \tag{71}$$

$$K^*_{T,t+1} = (1-\delta)K^*_{T,t} + I^*_{T,t} \tag{72}$$

$$K^*_{X,t+1} = (1-\delta)K^*_{X,t} + I^*_{X,t} \tag{73}$$

- Resource constraints:

$$Y_{N,t} = C_{N,t} + I_{N,t} \tag{74}$$

$$Y_{H,t} = C_{H,t} + C^*_{H,t} + I_{T,t} \tag{75}$$

$$Y^*_{N,t} = C^*_{N,t} + I^*_{N,t} \tag{76}$$

$$Y^*_{F,t} = C^*_{F,t} + C_{F,t} + I^*_{T,t} \tag{77}$$

$$Y^*_{X,t} = C_{X,t} + C^*_{X,t} + x_t + x^*_t + I^*_{X,t} \tag{78}$$

- Productivity shocks

$$\mathbb{A}_t = \rho \mathbb{A}^T_{t-1} + \varepsilon_t \tag{79}$$

D. The ST model

The equilibrium conditions under the ST model are given by equations (23)-(29), (35), (36), (41), (42), (45), (48)-(50), (52)-(57), (59), (63), (69)-(72), (74)-(77) and (79), and the following 10 equations.

$$C_{T,t} = (1-\gamma_1) p_{T,t}^{-\eta_1} C_t \tag{80}$$

$$C_{N,t} = \gamma_1 p_{N,t}^{-\eta_1} C_t \tag{81}$$

$$C^*_{T,t} = (1-\gamma_1) p_{T,t}^{*-\eta_1} C^*_t \tag{82}$$

$$C^*_{N,t} = \gamma_1 p_{N,t}^{*-\eta_1} C^*_t \tag{83}$$

$$1 = (1-\gamma_1) p_{T,t}^{1-\eta_1} + \gamma_1 p_{N,t}^{1-\eta_1} \tag{84}$$

$$1 = (1-\gamma_1) p_{T,t}^{*1-\eta_1} + \gamma_1 p_{N,t}^{*1-\eta_1} \tag{85}$$

$$Y_{H,t} = A_{T,t} K^{\alpha}_{T,t} L^{1-\alpha}_{T,t} \tag{86}$$

$$R_{t-1} = \frac{1}{p_{H,t-1}} \{(1-\delta) p_{H,t} + \alpha p_{H,t} \frac{Y_{H,t}}{K_{T,t}}\} \tag{87}$$

$$Y^*_{F,t} = A^*_{T,t} K^{*\alpha}_{T,t} L^{*1-\alpha}_{T,t} \tag{88}$$

$$R^*_{t-1} = \frac{1}{p^*_{F,t-1}} \{(1-\delta) p^*_{F,t} + \alpha p^*_{F,t} \frac{Y^*_{F,t}}{K^*_{T,t}}\} \tag{89}$$

Moreover, since there are no commodities in the ST model, $\gamma_2 = \gamma^*_2 = 0.5$ and $L^*_t = L^*_{T,t} + L^*_{N,t}$.

III. Transmission of U.S. Monetary Policy to Commodity Exporters and Importers

Abstract

This chapter studies international transmission of U.S. monetary policy shocks to commodity exporters and importers. I first show empirically that the shocks have stronger effects on commodity exporters than importers. Then, I augment a standard three-country model to include commodities. Consistently with the empirical evidence, in the model an expansionary monetary policy shock to the U.S. increases aggregate output of commodity exporters by more than that of importers. This is because the increased U.S. aggregate demand triggered by the shock leads to rises in its demand for commodities and the real commodity price, and thus commodity exporters' exports increase relative to those of commodity importers. Furthermore, I show that if commodity exporters' currency is pegged to the U.S. dollar, then the U.S. monetary policy shocks have stronger spillovers to commodity exporters and importers. In the event that the U.S. becomes a net energy exporter, the shocks will have weaker effects on commodity exporters and stronger impacts on importers.

1. Introduction

U.S. monetary policy has significant effects on prices of commodities such as oil, metal, wood, etc.[1] Since changes in commodity prices affect commodity-exporting and commodity-importing countries differently (see Bodenstein, Erceg and Guerrieri, 2011 and others), inter-

[1] For details, see Barsky and Kilian (2001), Anzuini, Lombardi and Pagano (2013), etc.

national transmissions of U.S. monetary policy shocks to the two groups may be different as well. I show empirically that in response to an expansionary U.S. monetary policy shock, output of commodity-exporting countries increases by more than that of commodity-importing countries. This result can be explained by a rise in commodity prices and a larger increase in exports of commodity-exporting countries than those of commodity-importing countries in response to the shock. Then, by extending the two-country real business cycle (RBC) model of Stockman and Tesar (1995) to a three-country setup, I construct a three-country dynamic stochastic general equilibrium (DSGE) model which includes commodities with consideration for idiosyncratic commodity trade structures of countries. According to the simulation results of the model, the aggregate output of commodity-exporting countries rises more compared to that of commodity-importing countries in response to an expansionary U.S. monetary policy shock. Since the shock increases U.S. demand for commodities and hence real commodity price, exports of commodity-exporting countries increases by more than those of commodity-importing countries. Therefore, U.S. monetary policy has stronger spillovers to commodity-exporting countries compared to commodity-importing countries, which is consistent with the empirical findings.

From the traditional view, U.S. monetary policy affects other countries through changes in trade flows and exchange rates (the Mundell-Flemming-Dornbusch (MFD) model). Recently, Rey (2016) argues that U.S. monetary policy has influences on other countries by affecting global financial cycles. Nonetheless, the importance of international transmission channel of monetary policy through changes in commodity prices has been raised many times in international meetings since 2008. For example, the Delhi Declaration in BRICS[2] Summit 2012 stated that "excessive liquidity from the aggressive policy actions taken by central banks in advanced countries to stabilize their domestic economies has been spilling over into emerging market economies, fostering excessive volatility in capital flows and commodity prices." According to Takáts and Vela (2014), in the Meeting of Deputy Governors in Basel in 2014, several central banks argued that monetary policies in advanced countries directly affect commodity prices, and hence macroeconomic conditions in emerging economies. From

[2] Brazil, Russia, India, China and South Africa

these sources as well as many empirical studies, we can expect that monetary policy in a large economy like the U.S. has strong impacts on commodity prices, and that changes in commodity prices triggered by monetary policy in a large economy affect economic conditions of other countries. As a result, many empirical studies have taken commodity prices into consideration to properly analyse international monetary transmission (see Canova, 2005; Maćkowiak, 2007; Dedola, Rivolta and Stracca, 2017; etc.).

To explain the mechanism briefly, an expansionary monetary policy shock in the U.S., a commodity-importing country,[3] will raise its output, which will lead to an increase in its demand for imports of commodities from commodity-exporting countries. In turn, the increased U.S demand for commodities will raise commodity prices. The increases in U.S. demand for imports of commodities and commodity prices will positively affect commodity-exporting countries. The rise in commodity prices, however, will have adverse influences on commodity-importing countries. Therefore, U.S. monetary policy would be expected to have stronger effects on commodity-exporting countries than on commodity-importing countries. In accordance with this expectation, an expansionary U.S. monetary policy shock has larger positive effects on output of commodity-exporting countries than commodity-importing countries as shown by the empirical analysis in Section 2.

In order to analyse international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries, I add commodities with consideration for different commodity trade structures to a standard three-country DSGE model. In the model, although country A (representing the U.S.) produces commodities, its production of commodities is not enough to meet domestic demand for commodities. Thus, it always imports commodities from commodity-exporting countries. Country B (representing commodity-importing countries among G-7 countries[4]) is the same as country A. Country C (representing the major commodity-exporting countries in the world[5]) produces commodities to meet

[3] The average ratio of net commodity exports to GDP in the U.S. was -7.5% during 2006-2011 according to OECD Trade in Value Added database. I define the commodity sector as agriculture, hunting, forestry, fishing, mining, quarrying, wood and basic metal industries following IMF's commodity price index.

[4] France, Germany, Italy, Japan and the U.K.

[5] Algeria, Angola, Argentina, Australia, Azerbaijan, Bahrain, Belize, Bolivia, Brazil, Brunei Darussalam, Canada, Cambodia, Cameroon, Chile, Colombia, Costa Rica, Côte d'Ivoire, Ecuador, Estonia, Finland,

domestic demand for commodities and the other countries' demand for imports of commodities, and thus always exports commodities. Furthermore, households' consumption basket includes commodities, and tradable good producing firms use commodities as an input. Finally, the model includes capital and investment. The simple DSGE model without capital and investment is typically used to study optimal monetary policy, because omitting these simplifies the analysis. However, the aim of this chapter is to study transmission of monetary policy rather than optimal monetary policy, and the transmission channel via changes in investment is important in transmission of monetary policy. For these reasons together with consistency with the model in Chapter 2, capital and investment are included in the model.[6]

The primary goal of this chapter is to examine whether U.S. monetary policy shocks have stronger effects on commodity-exporting countries than commodity-importing countries. Specifically, the goal is to show that in the model an expansionary monetary policy shock to the U.S. (country A) leads to a larger increase in aggregate output of commodity-exporting countries (country C) compared to commodity-importing countries (country B), consistently with the empirical evidence in Section 2.

This chapter concludes that, indeed, an expansionary monetary policy shock to the U.S. brings about a bigger increase in aggregate output of commodity-exporting countries than commodity-importing countries. To be specific, an expansionary monetary policy shock to the U.S. increases its aggregate output and consumption, and depreciates its exchange rate. The increased aggregate demand leads to a rise in its demand for imports of foreign tradable goods and commodities from foreign countries. The depreciation makes foreign tradable goods and commodities more expensive. Owing to the increased price, U.S. consumption of foreign tradable goods decreases, and hence its imports of foreign tradable goods fall. However, despite the increased price, U.S. commodity consumption goes up thanks to the complementarity between commodities and noncommodity goods in consumption. Conversely, since the

Iceland, Indonesia, Iran, Kazakhstan, Latvia, Luxembourg, Malaysia, Mexico, the Netherlands, New Zealand, Nigeria, Norway, Oman, Paraguay, Peru, Qatar, Russia, Saudi Arabia, South Africa, Ukraine, the U.A.E, Uruguay, Venezuela, Vietnam and Zambia

[6] I do not consider the inventory or storage of commodities in the model for the same reasons as in Chapter 2.

depreciation makes U.S. tradable goods cheaper, consumptions of U.S. tradable goods in all three countries increase, which causes a large increase in the output of U.S. tradable goods. U.S. imports of commodities for the tradable production jump. Therefore, U.S. imports of commodities from commodity-exporting countries rise, which leads to a rise in exports of commodity-exporting countries. On the contrary, exports of commodity-importing countries fall due to the decreased demand for their tradable goods. Consequently, aggregate output of commodity-exporting countries goes up by more compared to commodity-importing countries.

Furthermore, according to the simulation results, if commodity-exporting countries adopt a pegged exchange rate regime, i.e., their currency is pegged to the U.S. dollar, U.S. monetary policy shocks have stronger impacts on both commodity-exporting and commodity-importing countries than when the exchange rate regime of commodity-exporting countries is floating. If the U.S. becomes a net energy exporter as per the expectations of the U.S. Energy Inforamtion Administration (EIA), the effects of the shocks on commodity-exporting countries will become weaker but those on commodity-importing countries will become stronger.

The policy implications from the analysis are clear. Since outputs of commodity-exporting countries fluctuate by more depending on U.S. monetary policy than commodity-importing countries, their policymakers, especially those in commodity-exporting countries whose currencies are pegged to the U.S. dollar, should monitor U.S. economic conditions and monetary policy to stabilise their economies more carefully. Furthermore, if the U.S. becomes a net energy exporter as per the EIA's expectation, U.S. monetary policy will have stronger effects on commodity-importing countries than now, which means that U.S. economic conditions and monetary policy are becoming more and more important factors to policymakers in commodity-importing countries in stabilising their economies.

This chapter is closely related to the literature on international monetary transmission. The most well-known framework for this is the MFD model. According to the MFD model, a monetary loosening in the home country leads to a rise in its demand, which boosts the home country's imports from the foreign country (demand-augmenting effect). However, the monetary loosening brings about an exchange rate depreciation, which makes the foreign country's imports from the home country increase (the expenditure-switching effect). Since these two effects are opposite, the net effect of monetary policy in one country on the other country is ambiguous according to the MFD model. The other popular framework is developed by Svensson and van Wijnbergen (1989) and Obstfeld and Rogoff (1995). Their theoretical frameworks with micro-foundations have become the main analytical machinery. These models emphasize that a monetary loosening in the U.S. increases future U.S. price levels making future goods more expensive relative to current goods. This brings about intertemporal substituion in favour of current goods, and into current foreign goods, which has positive effects on foreign output. With regards to empirical studies, many papers (see Kim, 2001; Faust and Rogers, 2003; Dedola, Rivolta and Stracca, 2017; etc.) show that U.S. monetary policy has positive spillover effects on other countries. For instance, Kim (2001) concludes that since a monetary expansion in the U.S. decreases the world real interest rate and increases the world aggregate demand for U.S. and foreign goods, foreign output grows, which is suggested by some versions of Svensson and van Wijnbergen (1989) and Obstfeld and Rogoff (1995).

This chapter is organised as follows. Section 2 empirically shows that U.S. monetary policy shocks have stronger effects on commodity-exporting countries than on commodity-importing countries. Section 3 describes the three-country DSGE model with commodities. Section 4 presents the model calibration and analyses how U.S. monetary policy shocks affect commodity-exporting and commodity-importing countries differently. Also, if commodity-exporting countries adopt a pegged exchange rate regime and the U.S. becomes a net energy exporter, how the effects of U.S. monetary policy shocks change is analysed. Then, I draw policy implications from the analysis. Section 5 concludes.

2. Empirical evidence for the transmission mechanism

In this section, I investigate empirically the mechanism of how U.S. monetary policy shocks affect outputs of commodity-exporting and commodity-importing countries differently through changes in commodity prices and exports of the two groups. Specifically, I empirically examine whether an expansionary U.S. monetary policy shock leads to a rise in commodity prices and larger increases in exports and industrial production of commodity-exporting countries than those of commodity-importing countries.

I use the two step approach of Romer and Romer (2004), and Dedola, Rivolta and Stracca (2017). The first step is to identify U.S. monetary policy shocks using the vector autoregression (VAR) model with external instruments developed by Stock and Watson (2012) and Mertens and Ravn (2013). The second step is to estimate the effects of the shocks on commodity prices, and exports and industrial productions of commodity-exporting and commodity-importing countries by using autoregressive distributed lag models in which the lagged values of the shocks are included. Then, I investigate the robustness of the results from the two step approach by using an open economy VAR.

The reasons why I use the two step approach as main evidence rather than the open economy VAR are as follows. Although the two step approach is known to be sensitive to the lag length of autoregressive distributed lag models according to Coibion (2012), the VAR has the same shortcoming as well, i.e., it is very sensitive to the lag structure. Furthermore, to properly model an open economy VAR, we should model both U.S. and foreign economies in the VAR, which means many variables of the U.S. and foreign countries should be included in the VAR. However, if we include many variables in the VAR, we face the well-known "curse of dimensionality." In other words, if we add one more variable in the VAR, the number of parameters to estimate increases quadratically, which causes inefficient estimators. Due to these shortcomings, many open economy VARs that analyse international transmission of U.S. monetary policy shocks in the literature do not properly model the U.S., but include only U.S. monetary policy indicators in VARs (see Kim and Roubini, 2000; Gerko and Rey, 2017; etc.). In this chapter, I use the open economy VAR of Gerko and Rey (2017) for the robustness check.

2.1. Methodology

The first step is to obtain U.S. monetary policy shock series. I use the VAR with external instruments of Gertler and Karadi (2015) in which high frequency surprises around policy announcements are used as external instruments and government bond rates are used as the policy indicator. The VAR includes six U.S. variables and one instrument. The six variables are the log industrial production, the log CPI index, the one-year government bond rate (the policy indicator),[7] the excess bond premium of Gilchrist and Zakrajšek (2012), the mortgage rate spread and the commercial paper spread. The instrument is the unexpected changes in the three month ahead monthly federal funds futures within a 30-minute window of the Federal Open Market Committee (FOMC) announcement. The mortgage rate spread is defined as the difference between the 30-year conventional mortgage rate and the 10-year constant maturity treasury rate, and the commercial paper spread is the difference between the 3-month AA nonfinancial rate and the 3-month treasury rate. Since the excess bond premium of Gilchrist and Zakrajšek (2012) is only available to August 2016, I expand the data set of Gertler and Karadi (2015) to July 1979 to August 2016 (full sample) by using FRED data other than the instrument which is only available to me from January 1991 to June 2012. Therefore, I use the full sample in estimating coefficients and reduced form shocks, and then use the instrument and the estimated reduced form shocks for the corresponding period (January 1991 to June 2012) to find the relationship between the reduced form and structural form shocks. The lag length is 12 months. For the detailed methodology of the VAR with external instruments, see Appendix A.

The second step is to compute the impact of an expansionary U.S. monetary policy shock. I estimate the following autoregressive distributed lag model for each variable and country to obtain the impact.

$$\Delta y_t = \alpha + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \sum_{j=1}^{q} \gamma_j S_{t-j} + e_t \tag{1}$$

[7] According to Gertler and Karadi (2015), since the innovations of the government bond rate includes both the effects of surprises in the current federal funds rate and shocks to forward guidance, the government bond rate is appropriate for the policy indicator.

where y is the log commodity price index,[8] the log industrial production of each country or the exports of goods of each country.[9] S is U.S. monetary policy shocks obtained in the first step. p and q are the numbers of lags of y and S, respectively. I include 12 lags for y ($p = 12$) and 24 lags for S ($q = 24$).[10] The sample countries are 16 OECD countries whose monthly data is available from OECD Monthly Economic Indicators. Among them, 5 countries are commodity-exporting countries whose net commodity exports from the OECD Trade in Value Added are positive: Canada, Finland, Mexico, the Netherlands and Norway. 11 countries are commodity-importing countries: Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Japan, Spain, Sweden and the U.K.

The cumulative effect of one percentage point increase in S on y can be calculated from equation (1) as in Romer and Romer (2004). The effect on y after one month is γ_1, that after two months is $\gamma_1 + (\gamma_2 + \gamma_1\beta_1)$, and so on.

Finally, since the lag length in the VAR in the fisrt step is 12 months, U.S. monetary policy shock series start from July 1980. Therefore, the full sample of the second step is July 1980 to August 2016.

2.2. Results

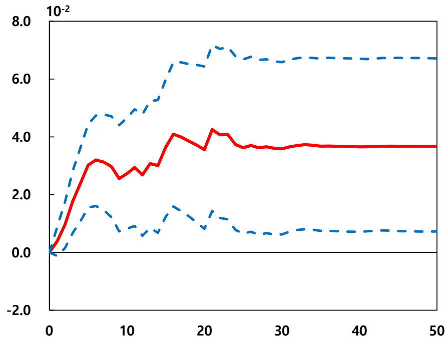
Figure 1 shows the cumulative impacts on variables of an expansionary U.S. monetary policy shock. For the cumulative impacts on exports and industrial productions of commodity-exporting and commodity-importing countries, I take the average cumulative impacts across the country groups. Consistently with other studies, there is a significant increase in commodity prices. The shock increases exports of commodity-exporting countries by more than those of commodity-importing countries. The shock leads to a significant increase in indus-

[8] The source of the commodity price index is the IMF. Since the natural gas price, whose weight in the commodity price index is 6.9%, starts from 1992, I exclude it from the commodity price index. Then, I construct the commodity price index by using the IMF's weight of each commodity price in the IMF's commodity price index.

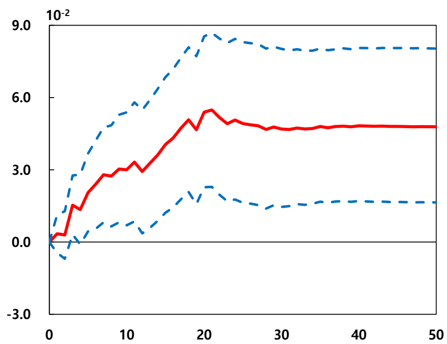
[9] The sources of the exports of goods and the industrial production of each country, which are seasonally adjusted, are the OECD Monthly Economic Indicators, and the exports are scaled by the average of the sum of imports and exports over the sample period.

[10] Since the results are sensitive to the lag length, for robustness, I also estimate equation (1) with $p = 24$ and $q = 36$, which are used in Romer and Romer (2004), and with $p = 24$ and $q = 24$. The estimated impacts of the two cases are very similar to the case with $p = 12$ and $q = 24$.

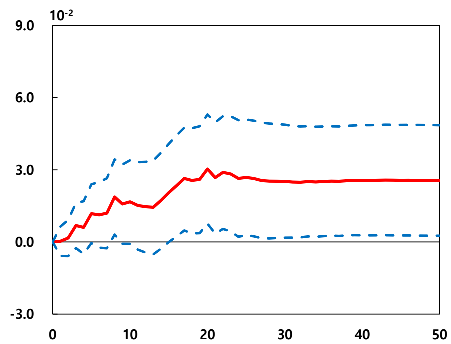
trial production of commodity-exporting countries, but the rise in industrial production of commodity-importing countries is barely statistically significant and is smaller, even if by not very much, than that of commodity-exporting countries.



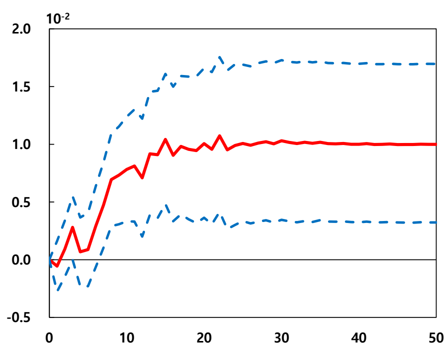
(a) Commodity prices



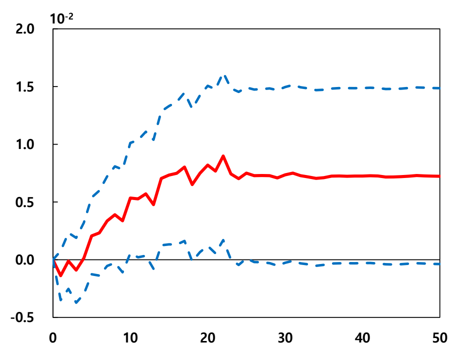
(b) Commodity exporters' exports



(c) Commodity importers' exports



(d) Commodity exporters' output



(e) Commodity importers' output

Figure 1: Cumulative effects of an expansionary U.S. monetary policy shock

Note: The solid lines are the median effect, and the dashed lines are 68% confidence intervals obtained by bootstrapping with 5,000 draws.

The main conclusion derived from this analysis is that the positive effects of an expansionary U.S. monetary policy shock on industrial production of commodity-exporting countries tend to be stronger than those on industrial production of commodity-importing countries.

A rise in commodity prices and a larger increase in exports of commodity-exporting countries than those of commodity-importing countries in response to the shock may explain the stronger effects on industrial production of commodity-exporting countries than commodity-importing countries of the shock. These are the main mechanisms of how U.S. monetary policy shocks have different effects on commodity-exporting and commodity-importing countries that the DSGE model in this chapter tries to capture.

2.3. Robustness

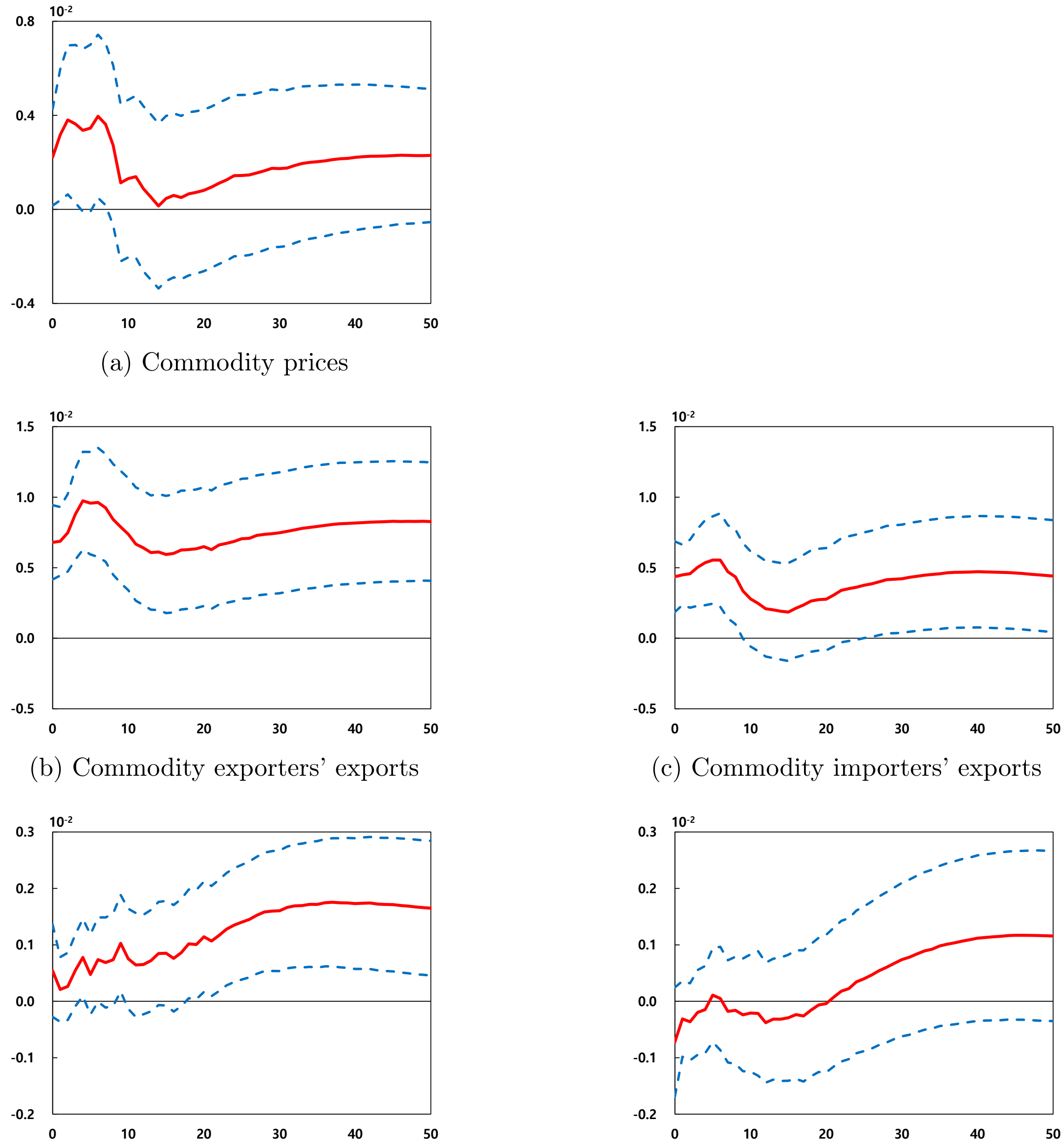
To check the robustness of the results from the two step approach, I use the open economy VAR with external instruments of Gerko and Rey (2017). Specifically, I use the same policy indicator and external instruments as those in Gertler and Karadi (2015) for U.S. monetary policy shocks, and estimate impulse responses of variables of commodity-exporting and commodity-importing countries to an expansionary U.S. monetary policy shock.

The VAR includes the U.S. one-year government bond rate as the U.S. policy indicator, the log commodity price index, and the log real effective exchange rate,[11] the exports of goods, the short-term interest rate[12] and the log industrial production of each country. As an external instrument, unexpected changes in the three month ahead monthly federal funds futures within a 30-minute window of the FOMC announcement are used. I use the dataset of Gertler and Karadi (2015) for the instrument. Although the instrument is only available January 1991 to June 2012, the full sample is January 1980 to August 2016.

I estimate each VAR for each country. For the impulse responses of the commodity price and the U.S. one-year government bond rate, I use the average impulse response of all countries, and for the impulse responses of the variables of commodity-exporting and commodity-importing countries I take the average impulse response across the country groups. The lag length is 12 months.

[11] The source of the real effective exchange rate of each country is the BIS.

[12] Central bank rate (Austria, Canada, Denmark, Finland and Japan), interbank rate less than 24 hours (France, Germany, Mexico, Spain, Sweden and the U.K.), 3-month interbank rate (Belgium, Italy and the Netherlands, Norway) or money market rate (Ireland) is used as the short-term interest rate. The source of central bank rate, interbank rate less than 24 hours, and 3-month interbank rate is the FRED, and that of the money market rate is the IMF IFS.



(a) Commodity prices

(b) Commodity exporters' exports

(c) Commodity importers' exports

(d) Commodity exporters' output

(e) Commodity importers' output

Figure 2: Impulse responses to an expansionary U.S. monetary policy shock

Note: The solid lines are the median impulse response, and the dashed lines are 68% confidence intervals obtained by bootstrapping with 5,000 draws.

Figure 2 presents impulse responses of the variables in the system to an expansionary U.S. monetary policy shock. They are very similar to the results of the two step approach. In response to the shock, commodity prices increase. Exports of commodity-exporting and commodity-importing countries also increase, and the rise in exports of the former group is larger than the latter group. The shock brings about a significant increase in industrial production of commodity-exporting countries, but the response of industrial production of commodity-importing countries is not statistically significant. These results mean that U.S. monetary policy shocks have stronger effects on commodity-exporting countries than on commodity-importing countries as in the results of the two step approach.

3. Model description

In this section, I describe the three-country DSGE model.[13] The model adds commodities and idiosyncratic commodity trade structures of countries to an otherwise standard three-country DSGE model. The world economy consists of three countries: country A (the U.S., a commodity-importing country), country B (commodity-importing countries), and country C (commodity-exporting countries). Although countries A and B produce commodities, they cannot produce sufficient amount of commodities to meet the domestic demand for commodities, and thus they import commodities from country C. Country C produces enough commodities to meet its domestic demand for commodities and the other countries' demand for imports of commodities, and hence it exports commodities to the other two countries. Labour is mobile between sectors but immobile between countries. Asset markets are complete.

3.1. Households

The utility function of the representative household in country $i \in \{A, B, C\}$[14], which allows for habit formation in consumption, is

$$U^i = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln(C_t^i - bC_{t-1}^i) - \frac{L_t^{i^{1+\chi}}}{1+\chi} \right) \tag{2}$$

where $\mathbb{E}$ is the expectations operation, β is the discount factor, C_t^i is the composite of tradable, nontradable and commodity consumption goods, b is the habit parameter, L_t^i is labour supply by households, and χ is the inverse of Frisch elasticity of labour supply.

[13] See Appendix B for the equilibrium conditions for the model.
[14] In this chapter, the superscript and subscript 'i', and the subscript 's' denote countries and sectors, respectively.

The corresponding budget constraint is

$$C_t^i + \mathbb{E}_t\{\mathscr{Q}_{t,t+1}^i D_{t+1}^i\} = \sum_s W_{s,t}^i L_{s,t}^i + D_t^i + \mathit{\Pi}_t^i \tag{3}$$

with $s \in \{T, N, X\}$ where 'T', 'N' and 'X' denote the tradable, nontradable and commodity sectors respectively, and $L_{s,t}^i$ is labour supply to sector s where $L_t^i = \sum_s L_{s,t}^i$. $\mathscr{Q}_{t,t+1}^i$, D_{t+1}^i, $W_{s,t}^i$ and $\mathit{\Pi}_t^i$ denote the stochastic discount factor for one-period ahead real pay-offs relevant to the household, the real pay-off in period $t+1$ of the portfolio held at the end of period t, the real wage in sector s and the profits remitted by firms, respectively. $\mathbb{E}_t[\mathscr{Q}_{t,t+1}^i]$ is related to the risk free rate, R_t^i, i.e. $\mathbb{E}_t[\mathscr{Q}_{t,t+1}^i] = 1/R_t^i$.

The composite of consumption goods, C_t^i, is defined by noncommodity consumption goods, $C_{NC,t}^i$, and commodity consumption goods, $C_{X,t}^i$, using the constant elasticity of substitution (CES) aggregator.

$$C_t^i = \left\{(1-\gamma_0^i)^{\frac{1}{\eta_0}} C_{NC,t}^{i\ \frac{\eta_0-1}{\eta_0}} + \gamma_0^{i\ \frac{1}{\eta_0}} C_{X,t}^{i\ \frac{\eta_0-1}{\eta_0}}\right\}^{\frac{\eta_0}{\eta_0-1}} \tag{4}$$

Assuming that commodities produced in each country are homogenous, the commodity consumption goods, $C_{X,t}^i$, is the sum of domestically produced commodities, $C_{X,i,t}^i$, and imported commodities from country C, $C_{X,C,t}^i$.

$$C_{X,t}^i = C_{X,i,t}^i + C_{X,C,t}^i \tag{5}$$

Since countries A and B are net commodity-importing countries, I further assume that countries A and B can produce only a fraction of the domestic demand for commodity consumption goods ($C_{X,i,t}^i = (1-\gamma)C_{X,t}^i,\ \ i \in \{A, B\}$). This means that they need to import commodities from country C ($C_{X,C,t}^i = \gamma C_{X,t}^i,\ \ i \in \{A, B\}$). Country C can fully produce its domestic demand for commodity consumption goods ($C_{X,C,t}^C = C_{X,t}^C$) so it does not need to import commodities. Furthermore, country C can also produce demand for imports of commodities from countries A and B ($C_{X,C,t}^A + C_{X,C,t}^B$).

The noncommodity consumption goods, $C^i_{NC,t}$, in turn, consist of tradable, $C^i_{T,t}$ and nontradable consumption goods, $C^i_{N,t}$.

$$C^i_{NC,t} = \left\{ (1-\gamma_1)^{\frac{1}{\eta_1}} C^{i\,\frac{\eta_1-1}{\eta_1}}_{T,t} + \gamma_1{}^{\frac{1}{\eta_1}} C^{i\,\frac{\eta_1-1}{\eta_1}}_{N,t} \right\}^{\frac{\eta_1}{\eta_1-1}} \tag{6}$$

The tradable consumption goods, $C^i_{T,t}$, is a function of tradable consumption goods produced in country i, $C^i_{i,t}$, tradable consumption goods produced in country $l \neq i$, $C^i_{l,t}$, and tradable consumption goods produced in country $m \neq i, l$, $C^i_{m,t}$. It is assumed that the weights of $C^i_{l,t}$ and $C^i_{m,t}$ in $C^i_{T,t}$ are equal for all i.

$$C^i_{T,t} = \left\{ (1-\gamma^i_2)^{\frac{1}{\eta_2}} C^{i\,\frac{\eta_2-1}{\eta_2}}_{i,t} + \left(\frac{\gamma^i_2}{2}\right)^{\frac{1}{\eta_2}} C^{i\,\frac{\eta_2-1}{\eta_2}}_{l,t} + \left(\frac{\gamma^i_2}{2}\right)^{\frac{1}{\eta_2}} C^{i\,\frac{\eta_2-1}{\eta_2}}_{m,t} \right\}^{\frac{\eta_2}{\eta_2-1}} \tag{7}$$

The corresponding price indices, P^i_t (CPI), $P^i_{X,t}$ (price of commodity consumption goods), $P^i_{NC,t}$ (price of noncommodity consumption goods) and $P^i_{T,t}$ (price of tradable consumption goods), are defined by

$$P^i_t = \left\{ (1-\gamma^i_0) P^{i\,1-\eta_0}_{NC,t} + \gamma^i_0 P^{i\,1-\eta_0}_{X,t} \right\}^{\frac{1}{1-\eta_0}} \tag{8}$$

$$P^i_{X,t} = (1-\gamma) P^i_{X,i,t} + \gamma P^i_{X,C,t} \tag{9}$$

$$P^i_{NC,t} = \left\{ (1-\gamma_1) P^{i\,1-\eta_1}_{T,t} + \gamma_1 P^{i\,1-\eta_1}_{N,t} \right\}^{\frac{1}{1-\eta_1}} \tag{10}$$

$$P^i_{T,t} = \left\{ (1-\gamma^i_2) P^{i\,1-\eta_2}_{i,t} + \frac{\gamma^i_2}{2} P^{i\,1-\eta_2}_{l,t} + \frac{\gamma^i_2}{2} P^{i\,1-\eta_2}_{m,t} \right\}^{\frac{1}{1-\eta_2}} \tag{11}$$

where $P^i_{X,i,t}$ is the price of domestically produced commodities, $P^i_{X,C,t}$ is the price of imported commodities from country C, $P^i_{N,t}$ is the price of nontradable consumption goods, $P^i_{i,t}$ is the price of domestically produced tradable consumption goods, $P^i_{l,t}$ is the price of tradable consumption goods produced in country $l \neq i$, and $P^i_{m,t}$ is the price of tradable consumption goods produced in country $m \neq i, l$.

3.2. Firms

3.2.1. Final goods firms

In each sector, there are a continuum of intermediate goods firms indexed by $j \in [0,1]$. They produce differentiated intermediate goods, $Y^i_{s,t}(j)$, at prices $P^i_{s,t}(j)$. Final goods firms bundle intermediate goods to produce final goods according to the following CES technology:

$$Y^i_{s,t} = \left(\int_0^1 Y^i_{s,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{12}$$

where $\varepsilon > 1$ is the elasticity of substitution among intermediate goods.

From the profit maximisation problem, the demand for each intermediate good is

$$Y^i_{s,t}(j) = \left(\frac{P^i_{s,t}(j)}{P^i_{s,t}} \right)^{-\varepsilon} Y^i_{s,t} \tag{13}$$

And the corresponding price index is

$$P^i_{s,t} = \left(\int_0^1 P^i_{s,t}(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}} \tag{14}$$

3.2.2. Intermediate goods firms

Nontradable and commodity intermediate goods are produced using labour and capital as inputs, while commodities as well as labour and capital are used in the production of tradable intermediate goods. All three countries produce tradable, nontradable and commodity intermediate goods with the same production function. Firms purchase capital at the end of period $t-1$ to produce goods in period t, and sell the non-depreciated capital back to capital good producers at the end of period t.

Nontradable intermediate good producers

Nontradable intermediate good producers produce output using labour and capital, and all three countries produce nontradable intermediate goods with the identical production function.

$$Y_{N,t}^{i}(j) = A_{N,t}^{i} K_{N,t}^{i}(j)^{\alpha_N} L_{N,t}^{i}(j)^{1-\alpha_N} \tag{15}$$

where $Y_{N,t}^{i}(j)$ is the output of firm j, $A_{N,t}^{i}$ is the common productivity in the sector, $K_{N,t}^{i}(j)$ is capital input of the firm, $L_{N,t}^{i}(j)$ is labour input of the firm, and $1-\alpha_N$ is the labour share of income.

Tradable intermediate good producers

Producing tradable intermediate goods requires producers to use commodities as well as capital and labour as inputs. The production function is a nested CES as in Kim and Loungani (1992).

$$Y_{i,t}^{i}(j) = A_{T,t}^{i}\{(1-a)K_{T,t}^{i}(j)^{\frac{\nu-1}{\nu}} + a x_{t}^{i}(j)^{\frac{\nu-1}{\nu}}\}^{\frac{\nu\alpha}{\nu-1}} L_{T,t}^{i}(j)^{1-\alpha} \tag{16}$$

where $Y_{i,t}^{i}(j)$, $A_{T,t}^{i}$, $K_{T,t}^{i}(j)$, $x_{t}^{i}(j)$ and $L_{T,t}^{i}(j)$ denote the output of firm j, the common productivity in the sector, capital input of the firm, commodity input of the firm and labour input of the firm, respectively. $1-\alpha$ is the labour share of income. a and ν determine the importance of commodities and the elasticity of substitution between capital and commodities.

Like commodity consumption goods, commodity input is the sum of domestically produced commodities and imported commodities from country C ($x_{t}^{i}(j) = x_{i,t}^{i}(j) + x_{C,t}^{i}(j)$). Countries A and B can produce only a fraction of $x_{t}^{i}(j)$ ($x_{i,t}^{i}(j) = (1-\gamma)x_{t}^{i}(j),\ \ i \in \{A, B\}$), while country C can produce $x_{t}^{C}(j)$ ($x_{C,t}^{C}(j) = x_{t}^{C}(j)$).

Commodity intermediate good producers

Commodity intermediate good producers use capital and labour as inputs to produce goods. The production function is Cobb-Douglas as in Huynh (2016).

$$Y_{X,t}^{i}(j) = A_{X,t}^{i} K_{X,t}^{i}(j)^{\alpha_X} L_{X,t}^{i}(j)^{1-\alpha_X} \tag{17}$$

where $Y_{X,t}^{i}(j)$, $A_{X,t}^{i}$, $K_{X,t}^{i}(j)$ and $L_{X,t}^{i}(j)$ are the output of firm j, the common productivity in the sector, capital input of the firm and labour input of the firm, respectivley. $1-\alpha_X$ is the labour share of income.

Note that for simplicity the price elasticity of commodity supply which is generally known to be inelastic in the short run and elastic in the long run is not considered in the model, although responses of commodity prices and commodity outputs to monetary policy shocks may be different according to the degree of elasticity.[15]

Price setting

Firms in each sector set prices based on Calvo price-setting. In each period, a fraction, $1-\theta$, of firms adjust their prices. This means that the probability a firm will be stuck with a price one period is θ. Thus, the first order condition for the optimal reset price in sector s, $P^{i,O}_{s,t}$, is

$$P^{i,O}_{s,t} = \frac{\varepsilon}{\varepsilon-1}\frac{\mathbb{E}_t \sum_{h=0}^{\infty}(\beta\theta)^h \lambda^i_{t+h} mc^i_{s,t+h} P^{i^{\varepsilon}}_{s,t+h} Y^i_{s,t+h}}{\mathbb{E}_t \sum_{h=0}^{\infty}(\beta\theta)^h \lambda^i_{t+h} P^{i^{\varepsilon}}_{s,t+h} P^{i^{-1}}_{t+h} Y^i_{s,t+h}} \tag{18}$$

where $mc^i_{s,t}$ is the real marginal cost in sector s, and λ^i_t is the marginal value of an extra unit of income.

Accordingly, the price index in sector s evolves according to

$$P^i_{s,t} = \left[(1-\theta)P^{i,O^{1-\varepsilon}}_{s,t} + \theta P^{i^{1-\varepsilon}}_{s,t-1}\right]^{\frac{1}{1-\varepsilon}} \tag{19}$$

3.2.3. Capital good producers

Capital good producers can convert final goods to capital goods in each sector. In each period, capital good producers buy $I^i_{s,t}$ of final goods and $(1-\delta_s)K^i_{s,t}$ of used capital at price $Q^i_{s,t}$, and then produce new capital goods, $K^i_{s,t+1}$ using technology F_I. The capital good producers' problem is given by

$$\max_{I^i_{s,t}} \mathbb{E}_t \sum_{h=0}^{\infty} \lambda^i_{t+h}\left[Q^i_{s,t+h}\left(1-F_I(I^i_{s,t+h}, I^i_{s,t+h-1})\right) I^i_{s,t+h} - p^i_{s,t} I^i_{s,t+h}\right] \tag{20}$$

[15] Detailed discussions with regards to the price elasticity of commodity supply are presented in the final chapter.

subject to the laws of motion for capital

$$K^i_{s,t+1} = (1-\delta_s)K^i_{s,t} + \left(1 - F_I(I^i_{s,t}, I^i_{s,t-1})\right) I^i_{s,t} \tag{21}$$

where $p^i_{s,t}$ is the real price of goods in sector s, and $F_I(I^i_{s,t}, I^i_{s,t-1}) = \frac{\xi}{2}\left(\frac{I^i_{s,t}}{I^i_{s,t-1}} - 1\right)^2$.

3.3. Monetary policy and resource constraints

Monetary authority in country i follows a standard Taylor-type rule.

$$i^i_t = \rho_I i^i_{t-1} + (1-\rho_I)\{\phi_\pi(\pi^i_t - \pi^i) + \phi_Y(\ln Y^i_t - \ln Y^i)\} + v^i_t \tag{22}$$

with $\ln v^i_t = \rho \ln v^i_{t-1} + u^i_t$. i^i_t is the nominal interest rate, v^i_t is an exogenous monetary policy shock, π^i_t is the CPI inflation, and Y^i_t is the aggregate ouput. The variables without time subscript 't' denote their steady state values. Fisher equation, $R^i_t = \mathbb{E}_t\left[i^i_t/\pi^i_{t+1}\right]$, gives the relationship between the nominal and real interest rates.

Finally, I complete the model description with a set of resource constraints. The output of nontradable goods in each country has to be the same as the country's consumption of nontradable goods and its investment.

$$Y^i_{N,t} = C^i_{N,t} + I^i_{N,t} \tag{23}$$

The output of tradable goods in each country must equal the world demand for the tradable goods produced in the country and its investment.

$$Y^i_{i,t} = C^i_{i,t} + C^l_{i,t} + C^m_{i,t} + I^i_{T,t}, \;\; l \neq i, \;\; m \neq i, l \tag{24}$$

In countries A and B, the commodity output is equal to domestically produced commodities for consumption and production of tradable goods and investment. The commodity output of country C has to equate with the world demand for commodities produced in it for consumption and production of tradable goods and its investment.

$$Y^{i}_{X,t} = C^{i}_{X,i,t} + x^{i}_{i,t} + I^{i}_{X,t}, \ \ i \in \{A, B\} \tag{25}$$

$$Y^{C}_{X,t} = C^{A}_{X,C,t} + C^{B}_{X,C,t} + C^{C}_{X,t} + x^{A}_{C,t} + x^{B}_{C,t} + x^{C}_{t} + I^{C}_{X,t} \tag{26}$$

4. Model analysis

4.1. Calibration

Table 1 gives the parameter values for the model. The values are based on U.S. quarterly data and symmetric in the three countries with exception of the commodity trade structures.

Some parameter values are the same as those in the standard literature. The discount factor, β, is 0.99, the inverse of Frisch elasticity of labour supply, χ, is set to 3, the elasticity of substitution between intermediate inputs, ε, is 6, and the probability that a price does not adjust, θ, is assumed to be 0.75 as in Galí and Monacelli (2005). Following Christiano, Eichenbaum and Evans (2005), I assume that the habit parameter, b, is 0.65 and the value for the parameter associated with the investment adjustment costs, ξ, is 2.5. I set the labour shares of income in the nontradable $(1 - \alpha_N)$ and tradable $(1 - \alpha)$ sectors to 0.56 and 0.61, respectively, as in Stockman and Tesar (1995). The depreciation rates of capitals for the tradable and nontradable productions, δ, are 0.025 as in the standard literature. The depreciation rate of capital for the commodity production is also 0.025 $(\delta_X = \delta)$ following Arora and Gomis-Porqueras (2011), and Huynh (2016) in which the depreciation rate of capital for energy production is the same as that for the production in other sectors. I borrow the parameter values in the monetary policy from Clarida, Galí and Gertler (1999), and Smets and Wouters (2005, 2007). The autoregressive parameter for the monetary policy rule, ρ_I, is 0.8, the policy weight on inflation, ϕ_π, is set to 1.5, and the policy weight on output gap, ϕ_Y, is 0.1. The autoregressive parameter for monetary policy shock, ρ, is set to 0.15. The correlation of the monetary policy shocks across countries is assumed to be 0.15.

The elasticity of substitution between capital and commodities in the tradable production, ν, is set to 1 as in Kim and Loungani (1992). I use 146.392 as the steady state ratio of capital to commodity inputs in the tradable production, K_T^i/x^i. This value is different from Dhawan and Jeske (2008) and others. Dhawan and Jeske (2008) assume that the steady state ratio of capital to energy inputs is 232, but in the model firms in the tradable sector use all commodities rather than only energy. Considering that the weight of energy in the IMF's commodity price index is 0.631, 146.392 as the steady state capital/commodity is suitable. Accordingly, the weight of commodities in the tradable production, a, is 0.162 which is consistent with the values of ν, K_T^i/x^i, β and δ.[16] The labour share of income in the commodity sector $(1-\alpha_X)$ is assumed to be 0.66 as in Chapter 2.

These parameter values generate the steady state ratio of investment to output in each sector in country A, $I_N^A/Y_N^A = 0.26$, $I_T^A/Y_T^A = 0.19$ and $I_X^A/Y_X^A = 0.20$, and the steady state ratio of aggregate investment to aggregate output, $I^A/Y^A = 0.23$, which is close to the value in the standard literature (0.25). Accordingly, the steady state ratio of output in the nontradable sector to aggregate output, Y_N^A/Y^A, is 0.51 which is very close to the average ratio of output in the service sector[17] to GDP for Q1 2005-Q4 2016[18] from the NIPA data (0.52), and steady state ratios of outputs in the tradable and commodity sectors to aggregate output (Y_A^A/Y^A and Y_X^A/Y^A) are 0.43 and 0.07, respectively.[19]

With regards to the parameters associated with consumption, I assume that the weight of commodity consumption goods in the composite of consumption goods, γ_0, is 0.11 which is consistent with the average ratio of commodity consumption[20] to total consumption for Q1 1992-Q4 2016 from the NIPA data. I set the elasticity of substitution between commodity and noncommodity consumption goods, η_0, to be 0.3 following Natal (2012). The weight of nontradable consumption goods in the noncommodity consumption goods, γ_1, is assumed

[16] Using the first order conditions of households and firms in steady state, $a = \frac{1}{1+(1/\beta-1+\delta)(K_T^i/x^i)^{\frac{1}{\nu}}}$.

[17] I use wholesale and retail trades, transportation and warehousing, finance, insurance, real estate, rental, leasing, professional and business services, educational services, health care, social assistance, arts, entertainment, recreation, accommodation, food services, and other services (except government) as the service sector.

[18] NIPA data on quarterly real gross output by industry is only available from 2005.

[19] Because country B is symmetric to country A, the ratios are the same. For country C, since it has identical production functions and parameter values associated with the functions, the ratio of investment to output in each sector is equal to that of countries A and B. However, steady state ratio of output in each sector to aggregate output is different from that of countries A and B, and $Y_N^C/Y^C = 0.55$, $Y_C^C/Y^C = 0.26$ and $Y_X^C/Y^C = 0.18$.

[20] Gasoline and other energy goods, plus food and beverages purchased for off-premises consumption

to be 0.562. Considering that commodities are also tradable, γ_1=0.562 implies that the steady state ratio of consumption of all tradable goods (commodities and tradable goods in the model) to nontradable consumption is 1, which is equal to Stockman and Tesar (1995)'s assumption. I set the value of the elasticity of substitution between tradable and nontradable consumption goods, η_1, to be 0.44 as in Stockman and Tesar (1995). The weight of tradable consumption goods produced in the foreign countries in the tradable consumption goods, γ_2, is assumed to be 0.5, which ensures that the steady state ratio of imported commodity and tradable consumption goods to total tradable consumption goods is 0.5, $(C^A_{X,C} + C^A_B + C^A_C)/(C^A_T + C^A_X) = 0.5$. This ratio is the same as that in Stockman and Tesar (1995). The elasticity of substitution between home and foreign tradable consumption goods, η_2, is 1.1 as in Bodenstein, Erceg and Guerrieri (2011). To generate the steady state net commodity imports over aggregate output to be 5% which is the same as the average of the ratios of net commodity imports to GDP for 1995-2011 from the OECD Trade in Value Added, the fraction of imported commodities in commodity consumption goods and commodity input in countries A and B, γ, is set to be 0.5. The weight of commodity consumption goods in the composite of consumption goods in country C, γ^C_0, is 0.037, and the weight of tradable consumption goods produced in the foreign countries in the tradable consumption goods in country C, γ^C_2, is 0.794, which is a result of the assumptions that the steady state values of aggregate consumptions and labours in the three countries are the same. As a result of this parameterisation, the steady state ratio of aggregate consumption to aggregate output in country A, C^A/Y^A, is 0.75 which is slightly greater than the average ratio of private consumption expenditure to GDP for Q1 1992-Q4 2016 from the NIPA data (0.66) but the same as the value in the standard quarterly literature (0.75).[21]

Under this parameterisation, the steady state ratio of aggregate output in country A to that in country B, Y^A/Y^B, is equal to 1, and the steady state ratio of aggregate output in country C to that in country A, Y^C/Y^A, is 0.99. These values are very close to the average ratio of U.S. GDP to aggregate GDP of commodity-importing G-7 countries (1.03) and the average ratio of aggregate GDP of major commodity-exporting countries in the world to U.S

[21] This parameterisation results in $C^C/Y^C = 0.75$.

GDP (0.93) for 2003-2016[22] from the IMF World Economic Outlook data. It should be noted that although different relative sizes of countries in the model lead to different responses of exchange rates in response to monetary policy shocks, they do not affect the main results of this chapter. Regardless of the relative size of the U.S., an expansionary monetary policy shock in the U.S. leads to increases in commodity prices and its imports of commodities, which benefits commodity-exporting countries. Conversely, the increased commodity prices have adverse effects on commodity-importing countries.

Table 1: Parameter values

Parameter	Value	Definition
β	0.99	Discount factor
χ	3	Inverse of Frisch elasticity of labour supply
ε	6	Elasticity of substitution between intermediate inputs
θ	0.75	Probability that price cannot be adjusted
b	0.65	Habit parameter
ξ	2.5	Parameter associated with investment adjustment costs
$1-\alpha_N$	0.56	Labour share in the nontradable sector
$1-\alpha$	0.61	Labour share in the tradable sector
δ	0.025	Depreciation rate of capital
ρ_I	0.8	Autoregressive parameter for the monetary policy rule
ϕ_π	1.5	Policy weight on inflation
ϕ_Y	0.1	Policy weight on output gap
ρ	0.15	Autoregressive parameter for monetary policy shocks
ν	1	Elasticity of substitution between commodities and capital in the tradable production
a	0.162	Parameter related to the weight of commodities in the tradable production
$1-\alpha_X$	0.66	Labour share in the commodity sector
γ_0	0.11	Weight of commodities in the composite of consumption goods in countries A and B
η_0	0.3	Elasticity of substitution between commodity and noncommodity goods
γ_1	0.562	Weight of nontradable goods in the noncommodity consumption goods
η_1	0.44	Elasticity of substitution between tradable and nontradable goods
γ_2	0.5	Weight of foreign tradable goods in the tradable consumption goods in countries A and B
η_2	1.1	Elasticity of substitution between home and foreign tradable goods
γ	0.5	Fraction of imported commodities in commodity consumption goods and commodity input
γ_0^C	0.037	Weight of commodities in the composite of consumption goods in country C
γ_2^C	0.794	Weight of foreign tradable goods in the tradable consumption goods in country C

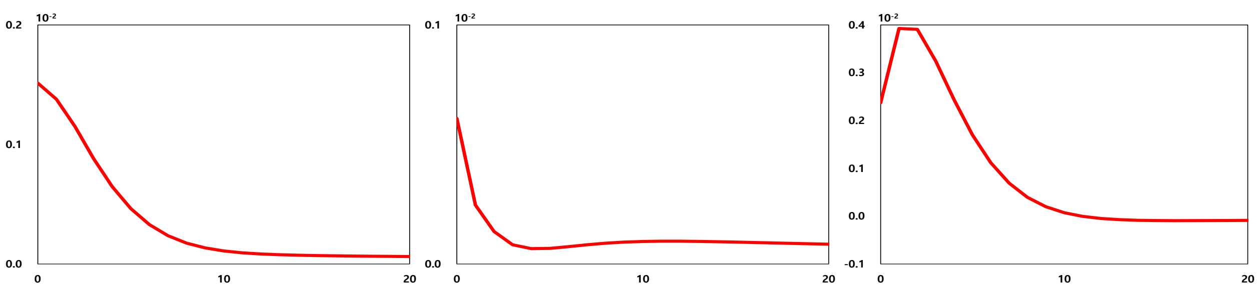
In addition, various values are used for parameters that are new due to the introduction of commodities, to evaluate whether the main results of the model are sensitive to the exact values of the parameters. These parameters are the depreciation rate of capital for the commodity production (δ_X), the elasticity of substitution between capital and commodities in the tradable production (ν), the labour shares of income in the commodity sector ($1-\alpha_X$), the weight of commodity consumption goods in the composite of consumption goods (γ_0),

[22] Some countries' GDPs are not available before 2003.

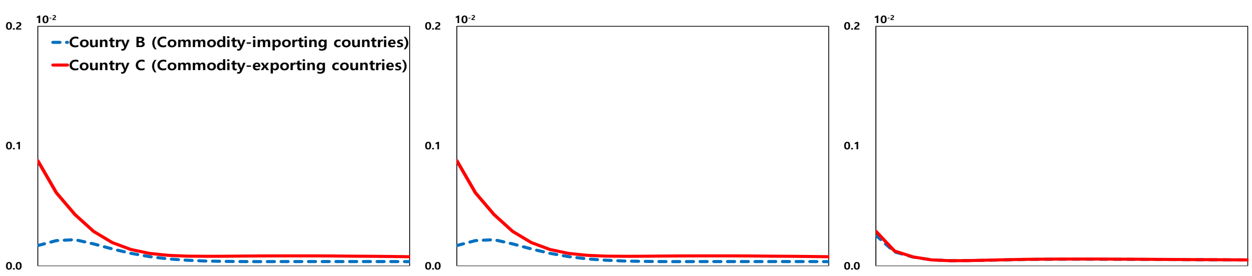
the elasticity of substitution between commodity and noncommodity consumption goods (η_0), and the fraction of imported commodities in commodity consumption goods and commodity input (γ).

4.2. Transmission of U.S. monetary policy shocks

In this section, I present responses of variables in the model to a negative 25bp monetary policy shock to country A (the U.S.). The size of the shock is based on the fact that one standard deviation of the estimated monetary policy shocks is about 25bp in Gertler and Karadi (2015) and the first step in Section 2 that used the expanded dataset of Gertler and Karadi (2015) is used is considered. In order to analyse how commodity-exporting and commodity-importing countries are affected differently by the shock, I compare responses of countries B (commodity-importing countries) and C (commodity-exporting countries).



(a) A's agg. output (b) A's agg. consumption (c) A's agg. investment



(d) Agg. outputs of B & C (e) Agg. consumptions of B & C (f) Agg. investments of B & C

Figure 3: Responses of aggregate variables to an expansionary monetary policy shock to country A

Figure 3 shows responses of aggregate variables in the three countries to an expansionary monetary policy shock to country A.[23] The shock decreases nominal interest rate, i^A, in

[23] Responses of all variables of the three countries are presented in Appendix C.

country A and thus its real interest rate, R^A. Accordingly, aggregate output, Y^A, aggregate consumption, C^A, and aggregate investment, I^A, in country A increase as usual.

The shock has positive spillovers to the other two countries. Aggregate outputs, Y^B and Y^C, aggregate consumptions, C^B and C^C, and aggregate investments, I^B and I^C, in countries B and C go up. However, the increases in aggregate variables of country C are larger than those of country B. Therefore, according to the model, U.S. monetary policy shocks have stronger impacts on commodity-exporting countries than on commodity-importing countries.[24]

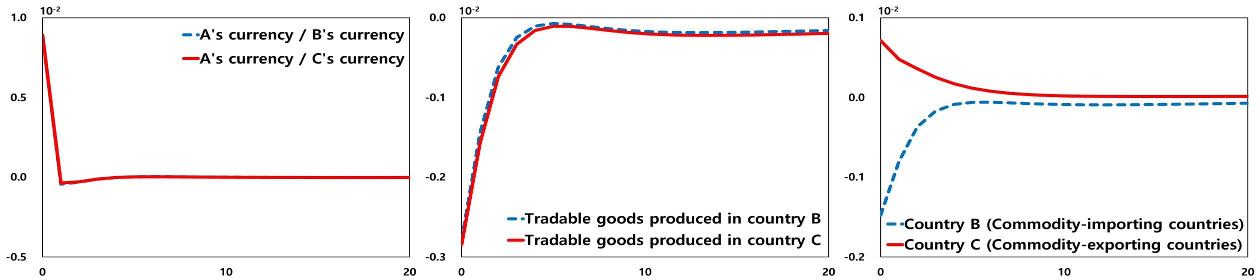
How commodity exporters and importers are affected differently

I now investigate how U.S. monetary policy shocks have stronger influences on commodity-exporting countries compared to commodity-importing countries. Figure 4 presents responses of several variables of countries B and C which are important in explaining different effects of an expansionary U.S. monetary policy shock.

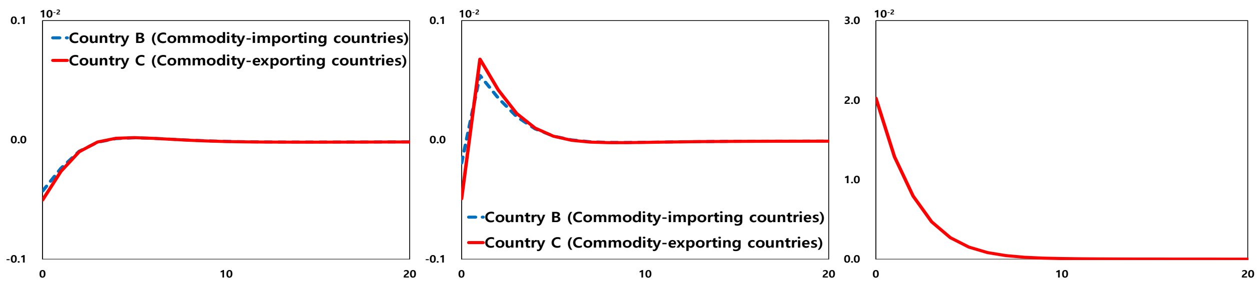
First, consider country B (commodity-importing countries). An expansionary monetary policy shock to country A (the U.S.) raises its aggregate demand and depreciates its currency against other two countries' currencies. The increased aggregate demand causes a rise in its demand for imports of foreign tradable goods. The depreciation has two effects. It offsets the increased demand for imports of foreign tradable goods in country A by making foreign tradable goods more expensive. Thus, in the model, country A's imports of tradable goods produced in the countries B and C fall. Conversely, the prices of country A's tradable goods in countries B and C become cheaper thanks to the depreciation, which leads to a decline in country C's imports of tradable goods produced in country B, and vice versa. Consequently, exports of country B drop. The second effect is that the depreciation leads the import price in country B to fall, which brings about a decrease in its CPI inflation. Owing to the decreased CPI inflation together with the positively correlated monetary policy shocks with country A,

[24] Whether these main results of the model are sensitive to changes in the values of parameters that are new due to the introduction of commodities is assessed in Appendix D. Sensitivity of the main results of the model to changes in the fraction of imported commodities in commodity consumption goods and commodity input, γ, is evaluated in Section 4.3.2.

the nominal interest rate in country B falls according to the monetary policy rule,[25] which has positive effects on country B's aggregate demand. Since the second effect is larger, its aggregate output increases in response to a monetary expansion in country A.



(a) Changes in nominal ex. rates (b) A's imports of foreign tradables (c) Exports



(d) Nominal interest rates (e) CPI inflation (f) A's commodity imports

Figure 4: Responses to an expansionary monetary policy shock to country A

With regard to country C (commodity-exporting countries), there is one more positive transmission channel through commodities. Specifically, an expansionary monetary policy shock to country A raises its demand for imports of commodities for consumption as well as foreign tradable goods. Similarly, the price of foreign commodities become more expensive due to the depreciation of U.S. currency. However, since the U.S. cannot produce enough commodities to meet the increased demand for consumption, it has to import more commodities from commodity-exporting countries. Furthermore, because all countries' consumptions of tradable goods produced in country A increase, country A's output of tradable goods rises, which leads to a jump in country A's commodity input in the production of tradable goods. Thus, the U.S. imports more commodities from country C. As a result, although country C's exports of its tradable goods fall, its total exports increase thanks to a large rise in exports of commodities. Accordingly, commodity output in country C goes up, which together with

[25] Even if monetary policy shocks to the three countries are not correlated, the decreased CPI inflations in countries B and C bring about falls in their nominal interest rates following the monetary policy rule.

the increased real commodity price[26] enables its aggregate output to rise by more compared to country B. Therefore, in the model the expansionary monetary policy shock to the U.S. has stronger positive spillovers to commodity-exporting countries than commodity-importing countries.

In short, an expansionary monetary policy shock to the U.S. increases its aggregate demand, and thus its demand for commodities and the real commodity price go up. Therefore, commodity-exporting countries' exports of commodities to the U.S. jump. The increased exports of commodities and the real commodity price enable the aggregate output of commodity-exporting countries to increase by more compared to commodity-importing countries.

Moreover, the model captures the empirical mechanism explained in Section 2, namely that an increase in the commodity prices and a bigger rise in exports of commodity-exporting countries than those of commodity-importing countries in response to an expansionary U.S. monetary policy shock explain the larger rise in output of commodity-exporting countries than commodity-importing countries. Specifically, in the model the commodity price increases and exports of commodity-exporting countries go up by more than those of commodity-importing countries in response to an expansionary U.S. monetary policy shock, which leads to a larger rise in the output of commodity-exporting countries compared to commodity-importing countries.

4.3. Further experiments

In this section, I consider two scenarios: commodity-exporting countries adopting a pegged exchange rate regime and the U.S. becoming a net energy-exporting country. This reflects the fact that the currencies of many emerging commodity-exporting countries such as Saudi Arabia and Venezuela are pegged to the U.S. dollar, and that according to the EIA, the U.S. could become a net energy-exporting country by 2026. Therefore, these two cases should be

[26] Because the nominal commodity price rises and the CPI inflation falls, the real commodity price goes up. Alternatively, since the U.S. demand for imports of commodities from country C increases due to the shock, the real price of commodities produced in country C rises.

considered.

4.3.1. Commodity-exporting countries adopting a pegged exchange rate regime

Since many emerging commodity-exporting countries such as Saudi Arabia, Qatar and Venezuela adopt pegged exchange rate regimes, the case in which the currency of commodity-exporting countries is pegged to the U.S. dollar and the exchange rate regime of commodity-importing countries is floating should be analysed.

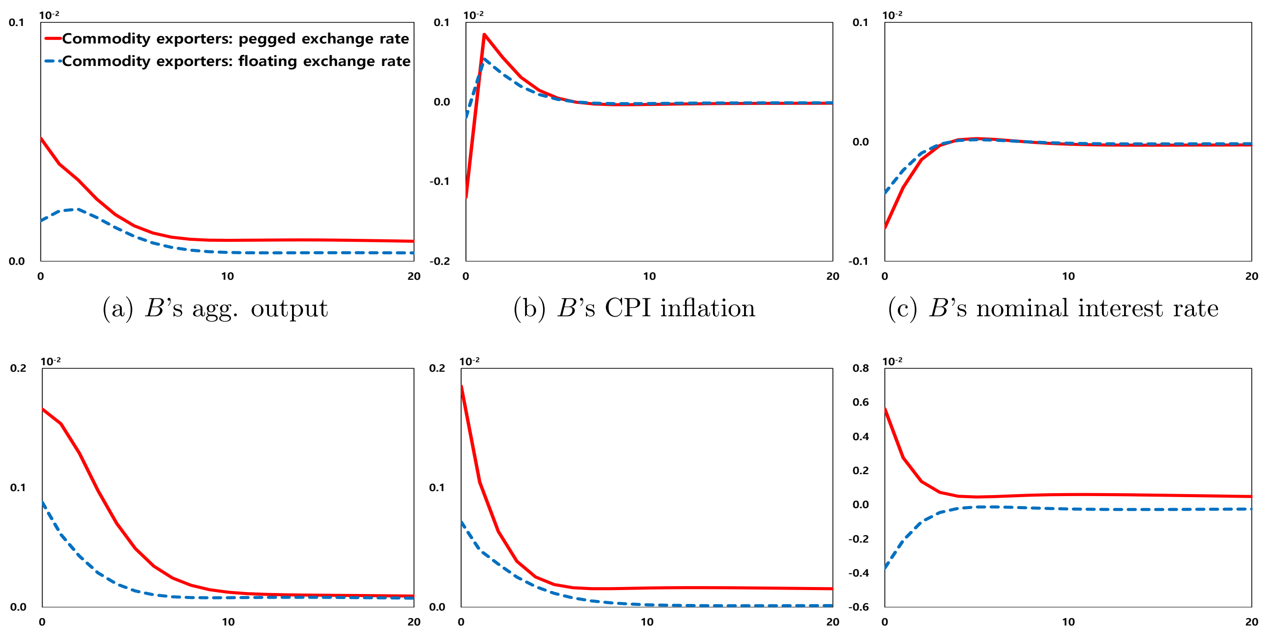
If country C's currency is pegged to country A's currency, the nominal exchange rate expressed by country A's currency per country C's currency, s_t^C, does not change.

$$s_t^C = s_{t-1}^C \tag{27}$$

From the uncovered interest rate parity, the pegged exchange rate also requires that the monetary authority in country C sets its nominal interest rate to be equal to that in country A ($i_t^A = i_t^C$).

Figure 5 shows responses of countries B and C to an expansionary monetary policy shock to country A in the models in which the currency of country C is pegged to the currency of country A and floating. First of all, even if country C adopts a pegged exchange rate regime, the shock has stronger effects on country C than on country B, i.e. the main results of the model are maintained. Nevertheless, when s_t^C is fixed, in response to the shock, aggregate output of country C increases by more than in the model in which country C's exchange rate regime is floating, which is consistent with conventional wisdom that a flexible exchange rate regime helps insulate the domestic economy from external shocks. Moreover, country B's aggregate output also goes up by more. Hence, if commodity-exporting countries adopt a pegged exchange rate regime, U.S. monetary policy shocks will have stronger impacts on both commodity-exporting and commodity-importing countries than the case in which commodity-exporting countries have a floating exchange rate regime.

To explain, since the currency of country C (commodity-exporting countries) is pegged to that of country A (the U.S.), it depreciates against the currency of country B (commodity-importing countries) like country A. Furthermore, the nominal interest rates of countries A and C fall by the exact same degree. The depreciations of the currencies of countries A and C lead to a larger fall in imported prices in country B, which causes a bigger fall in its CPI inflation. According to the monetary policy rule, country B cuts the nominal interest rate by more, which enables its aggregate output to increase by more compared to the model in which country C's exchange rate regime is floating. With regard to country C, the depreciation of its currency makes tradable goods and commodities produced in the country cheaper, which brings about a larger increase in its exports. The bigger rise in exports together with the larger fall in the nominal interest rate enables the aggregate output in country C to go up by more than the case in which country C adopts a floating exchange rate regime.



(a) B's agg. output (b) B's CPI inflation (c) B's nominal interest rate

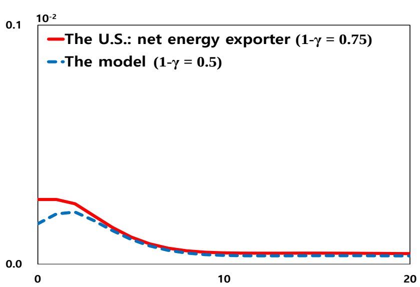
(d) C's agg. output (e) C's exports (f) C's tradable exports

Figure 5: Responses of countries B and C to an expansionary monetary policy shock to country A

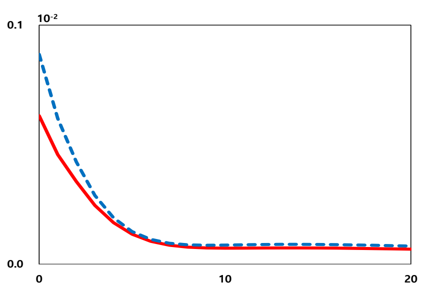
4.3.2. The U.S. as a net energy exporter

According to the EIA's Annual Energy Outlook 2017, the EIA expects that the U.S. could become a net energy-exporting country by 2026. Since the U.S. is a net importing country of other commodities such as basic metal and wood, even if the U.S. becomes a net energy-exporting country, it will not become a net commodity-exporting country. Rather, the U.S. is likely to shift from a major commodity-importing country to a minor commodity-importing country. This case can be considered by increasing the fraction of commodities that country A produces in its commodity consumption goods and commodity input, $(1-\gamma)$. To consider this case, I raise $(1-\gamma)$ from 0.5 to 0.75.

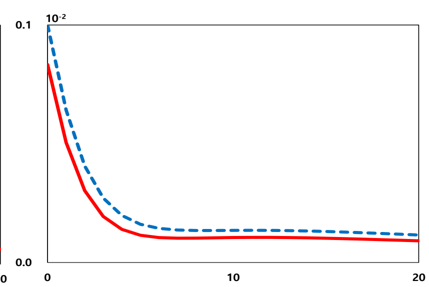
Figure 6 presents responses of countries B and C to an expansionary monetary policy shock to country A in the models in which the U.S. is a net energy-exporting country (a minor commodity-importing country) and a major commodity-importing country. Even if the U.S. is a minor commodity-importing country rather than a major commodity-importing country, the main results of the model are maintained, i.e. the shock has stronger effects on commodity-exporting countries than on commodity-importing countries. Nonetheless, when the U.S. is a minor commodity-importing country, aggregate ouput in country B (commodity-importing country) increases by more, and that in country C (commodity-exporting country) rises by less compared to the model in which the U.S. is a major commodity-importing country. Therefore, if the U.S. becomes a minor commodity-importing country, U.S. monetary policy shocks will have stronger spillovers to commodity-importing countries but weaker spillovers to commodity-exporting countries compared to the case in which the U.S. is a major commodity-importing country.



(a) B's agg. output



(b) C's agg. output



(c) Real commodity price in C

Figure 6: Responses of countries B and C to an expansionary monetary policy shock to country A

More specifically, since the U.S. can produce more commodities in the model in which the U.S. is a minor commodity-importing country, its demand for imports of commodities rises by less in response to the shock, which means that the real price of commodities produced in commodity-exporting countries goes up by less. This leads to a smaller rise in aggregate output of commodity-exporting countries compared to the case in which the U.S. is a major commodity-importing country. On the contrary, the smaller rise in the real commodity price benefits commodity-importing countries. Therefore, country B's aggregate output increases by more than the case in which the U.S. is a major commodity-importing country.

4.4. Policy implications

Important policy implications can be drawn from the analysis. Given that commodity-exporting countries are more vulnerable to U.S. monetary policy than commodity-importing countries, policymakers in commodity-exporting countries need to carefully monitor U.S. economic conditions and monetary policy to stabilise their economies. Considering that the economies of commodity-exporting countries whose currencies are pegged to the U.S. dollar fluctuate by much more in response to U.S. monetary policy, their policymakers are required to consider U.S. economic conditions and monetary policy more carefully. Specifically, because the Fed has raised the federal funds rate since the end of 2015, commodity-exporting countries will be more likely to be adversely affected. Policymakers in commodity-exporting countries should take this into account when conducting economic policies.

Furthermore, according to the simulation results, if the U.S. becomes a net energy-exporting country as per the expectations of the EIA, U.S. monetary policy will have stronger effects on commodity-importing countries than now. This also has important policy implications for policymakers in commodity-importing countries that U.S. economic conditions and monetary policy are becoming more and more important in stabilising their economies.

5. Conclusion

In this chapter, I analyse international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries. I first show empirically that an expansionary U.S. monetary policy shock tends to have stronger influences on commodity-exporting countries than on commodity-importing countries. This is because in response to the shock commodity prices rise and exports of commodity-exporting countries go up by more than those of commodity-importing countries. Then, I set up a three-country DSGE model in which commodities and idiosyncratic commodity trade structures of countries are considered, and show that responses of the model to an expansionary monetary policy shock in the U.S. capture the empirical mechanism well. Specifically, the increased aggregate demand in the U.S. triggered by the shock leads to rises in its demand for commodities and real commodity prices. Hence, commodity-exporting countries' exports of commodities to the U.S. increase, which leads to a larger increase in exports of commodity-exporting countries than those of commodity-importing countries. Consequently, the aggregate output of commodity-exporting countries goes up by more compared to commodity-importing countries.

Furthermore, I show that if commodity-exporting countries' currencies are pegged to the U.S. dollar, U.S. monetary policy shocks will affect both commodity-exporting and commodity-importing countries by more than when the exchange rate regime of commodity-exporting countries is floating. And if the U.S. becomes a net energy-exporting country meaning that the U.S. shifts from a major commodity-importing country to a minor commodity-importing country, U.S. monetary policy shocks will have weaker effects on commodity-exporting countries and stronger impacts on commodity-importing countries.

From the analysis, I draw several policy implications. Policymakers in commodity-exporting countries, especially adopting pegged exchange rate regimes, should monitor U.S. economic conditions and monetary policy more carefully. In addition, as the U.S. becomes a net energy-exporting country, importance of U.S. economic conditions and monetary policy in stabilising economies of commodity-importing countries will grow.

References

Anzuini, A., M. J. Lombardi, and P. Paganoa (2013). The impact of monetary policy shocks on commodity prices. *International Journal of Central Banking 9*, 119–144.

Arora, V. and P. Gomis-Porqueras (2011). Oil price dynamics in a real business cycle model. CAMA Working Paper 17/2011, Australian National University.

Barsky, R. B. and L. Kilian (2001). Do we really know that oil caused the great stagflation? A monetary alternative. NBER Working Paper Series 8389.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2011). Oil shocks and external adjustment. *Journal of International Economics 83*, 168–184.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*, 1–45.

Clarida, R., J. Galí, and M. Gertler (1999). The science of monetary policy: A new Keynesian perspective. *Journal of Economic Literature 37*, 1661–1707.

Clarida, R., J. Galí, and M. Gertler (2002). A simple framework for international monetary policy analysis. *Journal of Monetary Economics 49*, 879–904.

Coibion, O. (2012). Are the effects of monetary policy shocks big or small? *American Economic Journal: Macroeconomics 4*, 1–32.

Corsetti, G., L. Dedola, and S. Leduc (2008). International risk sharing and the transmission of productivity shocks. *Review of Economic Studies 75*, 443–473.

Dedola, L., G. Rivolta, and L. Stracca (2017). If the Fed sneezes, who catches a cold? *Journal of International Economics 108*, s23–s41.

Dhawan, R. and K. Jeske (2008). Energy price shocks and the macroeconomy: The role of consumer durables. *Journal of Money, Credit and Banking 40*, 1357–1377.

Faust, J. and J. H. Rogers (2003). Monetary policy's role in exchange rate behavior. *Journal of Monetary Economics 50*, 1403–1424.

Galí, J. and T. Monacelli (2005). Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies 72*, 707–734.

Gerko, E. and H. Rey (2017). Monetary policy in the capitals of capital. *Journal of the European Economic Association 15*, 721–745.

Gertler, M. and P. Karadi (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics 7*, 44–76.

Gilchrist, S. and E. Zakrajšek (2012). Credit spreads and business cycle fluctuations. *American Economic Review 102*, 1692–1720.

Huynh, B. T. (2016). Macroeconomic effects of energy price shocks on the business cycle. *Macroeconomic Dynamics 20*, 623–642.

Kim, I. and P. Loungani (1992). The role of energy in real business cycle models. *Journal of Monetary Economics 29*, 173–189.

Kim, S. (2001). International transmission of U.S. monetary policy shocks: Evidence from VAR's. *Journal of Monetary Economics 48*, 339–372.

Kim, S. and N. Roubini (2000). Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach. *Journal of Monetary Economics 45*, 561–586.

Maćkowiak, B. (2007). External shocks, U.S. monetary policy and macroeconomic fluctuations in emerging markets. *Journal of Monetary Economics 54*, 2512–2520.

Mertens, K. and M. O. Ravn (2013). The dynamic effects of personal and corporate income tax changes in the United States. *American Economic Review 103*, 1212–1247.

Natal, J.-m. (2012). Monetary policy response to oil price shocks. *Journal of Money, Credit and Banking 44*, 53–101.

Obstfeld, M. and K. Rogoff (1995). Exchange rate dynamics redux. *Journal of Political Economy 103*, 624–660.

Ramey, V. A. (2016). Macroeconomic shocks and their propagation. NBER Working Papers 21978.

Rey, H. (2016). International channels of transmission of monetary policy and the Mundellian trilemma. *IMF Economic Review 64*, 6–35.

Romer, C. D. and D. H. Romer (2004). A new measure of monetary shocks: Derivation and implications. *American Economic Review 94*, 1055–1084.

Smets, F. and R. Wouters (2005). Comparing shocks and frictions in US and Euro area business cycles: A Bayesian DSGE approach. *Journal of Applied Econometrics 20*, 161–183.

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review 97*, 586–606.

Stock, J. H. and M. W. Watson (2012). Disentangling the channels of the 2007-2009 recession. *Brookings Papers on Economic Activity 42*, 81–135.

Stockman, A. C. and L. L. Tesar (1995). Tastes and technology in a two-country model of the business cycle: Explaining international comovements. *American Economic Review 85*, 168–185.

Svensson, L. and S. van Wijnbergen (1989). Excess capacity, monopolistic competition and international transmission of monetary disturbances. *Economic Journal 99*, 785–805.

Takáts, E. and A. Vela (2014). International monetary policy transmission. BIS Papers No. 78.

Appendix

A. Methodology of the VAR with external instruments

Let y_t be a $n \times 1$ vector where n is the number of variables. Then, the general structural form of the VAR is

$$Ay_t = \sum_{j=1}^{p} C_j y_{t-j} + \varepsilon_t \tag{28}$$

where A is a $n \times n$ matrix of coefficients, C_j, $j = 1, 2, ..., p$ are $n \times n$ matrices of coefficients, and ε_t is a $n \times 1$ vector of structural shocks. By multiplying both sides of equation (28) by A^{-1}, the reduced form can be obtained.

$$y_t = \sum_{j=1}^{p} B_j y_{t-j} + u_t \tag{29}$$

where u_t is a $n \times 1$ vector of reduced form shocks. From equations (28) and (29), the relationship between u_t and ε_t can be written as

$$Au_t = \varepsilon_t, \;\; u_t = S\varepsilon_t \tag{30}$$

where $S = A^{-1}$. Since $\mathbb{E}[\varepsilon_t \varepsilon_t^T] = I$ where I is a $n \times n$ identity matrix and the superscript 'T' denotes transpose, the $n \times n$ variance-covariance matrix of the reduced form is

$$\Sigma = \mathbb{E}[u_t u_t^T] = \mathbb{E}[S\varepsilon_t \varepsilon_t^T S^T] = \mathbb{E}[SS^T] \tag{31}$$

Let the first element of y_t (y_t^1) be the policy indicator. Then, the first element of ε_t (ε_t^1) is the associated policy shock. To obtain impulse responses of variables to the policy shock, we need to identify only the first columns of S ($[s^1, s^2, \cdots, s^n]^T$), since we can obtain estimates of B_j by using least squares estimation of equation (29).

Let z_t be the instrumental variable for the policy shock. In order for z_t to be a valid instrument, following conditions should be satisfied.

$$\mathbb{E}[z_t\varepsilon_t^1] \neq 0,\ \ \mathbb{E}[z_t\varepsilon_t^2] = \mathbb{E}[z_t\varepsilon_t^3]\cdots = \mathbb{E}[z_t\varepsilon_t^n] = 0 \tag{32}$$

where $\varepsilon_t^k,\ \ k = 2, 3, \cdots, n$ means the kth element of ε_t.

Let $\hat{u}_t$ be the estimate of u_t by OLS of equation (29), and let $\hat{u_t}^h,\ \ h = 1, 2, \cdots, n$ be the hth element of $\hat{u}_t$. To obtain estimates of $[s^1, s^2, \cdots, s^5]^T$, first, regress $\hat{u_t}^1$ on z_t and obtain the fitted value of $\hat{\hat{u}}_t^1$. By doing this, we can isolate the variations in $\hat{u_t}^1$ owing to the structural policy shock (ε_t^1). Then, regress $\hat{u_t}^k,\ \ k = 2, 3, \cdots, n$ on $\hat{\hat{u}}_t^1$. Since the coefficient of this regression means the variation of $\hat{u_t}^k$ caused by the variations in $\hat{u_t}^1$ owing to ε_t^1, it is s^k/s^1.

$$\hat{u_t}^k = \frac{s^k}{s^1}\hat{\hat{u}}_t^1 + \varsigma_t \tag{33}$$

If we can find s^1, other elements of the first column of S are easily found from the estimates of equation (33). s^1 can be obtained from equations (31) and (33). First, partition S and Σ. Then, from equation (31),

$$S = \begin{pmatrix} s^1 & s_{1,2} \\ s_{2,1} & s_{2,2} \end{pmatrix},\ \ \Sigma = \begin{pmatrix} \mathit{\Sigma}_{1,1} & \Sigma_{1,2} \\ \mathit{\Sigma}_{2,1} & \Sigma_{2,2} \end{pmatrix} = \begin{pmatrix} s^1 & s_{1,2} \\ s_{2,1} & s_{2,2} \end{pmatrix}\begin{pmatrix} s^1 & s_{1,2} \\ s_{2,1} & s_{2,2} \end{pmatrix}^T \tag{34}$$

Then, $(s^1)^2 = \mathit{\Sigma}_{1,1} - s_{1,2}s_{1,2}^T$ where $s_{1,2}s_{1,2}^T = \left(\mathit{\Sigma}_{2,1} - \frac{s_{2,1}}{s^1}\mathit{\Sigma}_{1,1}\right)^T Q^{-1}\left(\mathit{\Sigma}_{2,1} - \frac{s_{2,1}}{s^1}\mathit{\Sigma}_{1,1}\right)$ with $Q = \frac{s_{2,1}}{s^1}\mathit{\Sigma}_{1,1}\frac{s_{2,1}^T}{s^1} - \left(\mathit{\Sigma}_{2,1}\frac{s_{2,1}^T}{s^1} + \frac{s_{2,1}}{s^1}\mathit{\Sigma}_{2,1}^T\right) + \Sigma_{2,2}$. Therefore, the ordering of variables is arbitrary in this framework.

Nonetheless, to identify the policy shocks we need to find the values of elements in the first row of A, $[a_{11}, a_{12}, \cdots, a_{1n}]$ with $a_{11} = 1$ due to a normalisation. The method to obtain these values is explained well in Ramey (2016). First, regress $\hat{u_t}^h,\ \ h = 2, \cdots, n$ on $\hat{u_t}^1$ using the instrument z_t, which yields unbiased estimates of the elements in the first column of A, $-a_{21}, -a_{31}, \cdots, -a_{n1}$. Then, regress $\hat{u_t}^1$ on $\hat{u_t}^h,\ \ h = 2, \cdots, n$ using $\hat{v_t}^h,\ \ h = 2, \cdots, n$ as instruments where $\hat{v_t}^h,\ \ h = 2, \cdots, n$ are residuals of previous regressions. This gives unbiased estimates of $-a_{12}, -a_{13}, \cdots, -a_{1n}$. Therefore, the estimate of the policy shocks can be obtained from

$$\hat{\varepsilon}_t^1 = \hat{u}_t{}^1 - a_{12}\hat{u}_t{}^2 - a_{13}\hat{u}_t{}^3 \cdots - a_{1n}\hat{u}_t{}^n \tag{35}$$

B. Equilibrium conditions of the model

In this appendix, I present the equilibrium system of the three-country DSGE model with commodities and different commodity trade structures of countries described in Section 3.

- Households' intertemporal problem:

$$\lambda_t^i = \frac{1}{C_t^i - bC_{t-1}^i} - \beta b \mathbb{E}_t \left[\frac{1}{C_{t+1}^i - bC_t^i} \right] \tag{36}$$

$$1 = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}^i}{\lambda_t^i} R_t^i \right] \tag{37}$$

$$\lambda_t^i W_{T,t}^i = L_t^{i\chi} \tag{38}$$

$$\lambda_t^i W_{N,t}^i = L_t^{i\chi} \tag{39}$$

$$\lambda_t^i W_{X,t}^i = L_t^{i\chi} \tag{40}$$

$$\lambda_t^l = \vartheta e_t^l \lambda_t^A, \;\; l \in \{B, C\} \tag{41}$$

where e_t^l denotes the real exchange rate between countries A and $l \in \{B, C\}$, and $L_t^i = \sum_s L_{s,t}^i$.

- Households' consumption allocation:

$$C_{NC,t}^i = (1 - \gamma_0^i) p_{NC,t}^{i-\eta_0} C_t^i \tag{42}$$

$$C_{X,t}^i = \gamma_0^i p_{X,t}^{i-\eta_0} C_t^i \tag{43}$$

$$C_{X,i,t}^i = (1 - \gamma) C_{X,t}^i, \;\; i \in \{A, B\} \tag{44}$$

$$C_{X,C,t}^C = C_{X,t}^C \tag{45}$$

$$C^i_{X,C,t} = \gamma C^i_{X,t}, \;\; i \in \{A, B\} \tag{46}$$

$$C^i_{T,t} = (1-\gamma_1)\left(\frac{p^i_{T,t}}{p^i_{NC,t}}\right)^{-\eta_1} C^i_{NC,t} \tag{47}$$

$$C^i_{N,t} = \gamma_1 \left(\frac{p^i_{N,t}}{p^i_{NC,t}}\right)^{-\eta_1} C^i_{NC,t} \tag{48}$$

$$C^i_{i,t} = (1-\gamma^i_2)\left(\frac{p^i_{i,t}}{p^i_{T,t}}\right)^{-\eta_2} C^i_{T,t} \tag{49}$$

$$C^i_{B,t} = \frac{\gamma^i_2}{2}\left(\frac{p^i_{l,t}}{p^i_{T,t}}\right)^{-\eta_2} C^i_{T,t}, \;\; l \neq i \tag{50}$$

$$C^i_{C,t} = \frac{\gamma^i_2}{2}\left(\frac{p^i_{m,t}}{p^i_{T,t}}\right)^{-\eta_2} C^i_{T,t}, \;\; m \neq i, l \tag{51}$$

- Price indices:

$$1 = (1-\gamma^i_0) p^{i^{1-\eta_0}}_{NC,t} + \gamma_0 p^{i^{1-\eta_0}}_{X,t} \tag{52}$$

$$p^i_{X,t} = (1-\gamma) p^i_{X,i,t} + \gamma p^i_{X,C,t}, \;\; i \in \{A, B\} \tag{53}$$

$$p^C_{X,t} = p^C_{X,C,t} \tag{54}$$

$$p^{i^{1-\eta_1}}_{NC,t} = (1-\gamma_1) p^{i^{1-\eta_1}}_{T,t} + \gamma_1 p^{i^{1-\eta_1}}_{N,t} \tag{55}$$

$$p^{i^{1-\eta_2}}_{T,t} = (1-\gamma^i_2) p^{i^{1-\eta_2}}_{i,t} + \frac{\gamma^i_2}{2} p^{i^{1-\eta_2}}_{l,t} + \frac{\gamma^i_2}{2} p^{i^{1-\eta_2}}_{m,t}, \; l \neq i, \; m \neq i, l \tag{56}$$

- Laws of one price:

$$p^A_{A,t} = e_{B,t} p^B_{A,t} \tag{57}$$

$$p^A_{B,t} = e_{B,t} p^B_{B,t} \tag{58}$$

$$p^A_{C,t} = e_{B,t} p^B_{C,t} \tag{59}$$

$$p^A_{X,C,t} = e_{B,t} p^B_{X,C,t} \tag{60}$$

$$p^A_{A,t} = e_{C,t} p^C_{A,t} \tag{61}$$

$$p^A_{B,t} = e_{C,t} p^C_{B,t} \tag{62}$$

$$p^A_{C,t} = e_{C,t} p^C_{C,t} \tag{63}$$

$$p^A_{X,C,t} = e_{C,t} p^C_{X,C,t} \tag{64}$$

- Nontradable intermediate good producing firms' optimality conditions and price setting

$$Y^i_{N,t} v^{p,i}_{N,t} = A^i_{N,t} K^{i^{\alpha_N}}_{N,t} L^{i^{1-\alpha_N}}_{N,t} \tag{65}$$

$$W^i_{N,t} = (1-\alpha_N) mc^i_{N,t} \frac{v^{p,i}_{N,t} Y^i_{N,t}}{L^i_{N,t}} \tag{66}$$

$$R^i_{t-1} = \frac{1}{Q^i_{N,t-1}} \{(1-\delta) Q^i{}_{N,t} + \alpha_N mc^i_{N,t} \frac{v^{p,i}_{N,t} Y^i_{N,t}}{K^i_{N,t}}\} \tag{67}$$

$$v^{p,i}_{N,t} = (1-\theta) \left[\frac{\varepsilon}{\varepsilon-1} \frac{\Delta^i_{1,N,t}}{p^i_{N,t} \Delta^i_{2,N,t}} \right]^{-\varepsilon} + \theta v^{p,i}_{N,t-1} \pi^{i^{\varepsilon}}_{N,t} \tag{68}$$

$$\pi^{i^{1-\varepsilon}}_{N,t} = (1-\theta) \left[\frac{\varepsilon}{\varepsilon-1} \frac{\pi^i_{N,t}}{p^i_{N,t}} \frac{\Delta^i_{1,N,t}}{\Delta^i_{2,N,t}} \right]^{1-\varepsilon} + \theta \tag{69}$$

$$\Delta^i_{1,N,t} = \lambda^i_t Y^i_{N,t} mc^i_{N,t} + \beta\theta \mathbb{E}_t \left[\Delta^i_{1,N,t+1} \pi^{i^{\varepsilon}}_{N,t+1} \right] \tag{70}$$

$$\Delta^i_{2,N,t} = \lambda^i_t Y^i_{N,t} + \beta\theta \mathbb{E}_t \left[\Delta^i_{2,N,t+1} \frac{\pi^{i^{\varepsilon}}_{N,t+1}}{\pi^i_{t+1}} \right] \tag{71}$$

$$\pi^i_{N,t} = \pi^i_t \frac{p^i_{N,t}}{p^i_{N,t-1}} \tag{72}$$

where $v^{p,i}_{s,t}$ denotes the price dispersion term in sector s.

- Tradable intermediate good producing firms' optimality conditions and price setting:

$$Y^i_{i,t} v^{p,i}_{T,t} = A^i_{T,t} \{(1-a) K^{i^{\frac{\nu-1}{\nu}}}_{T,t} + a x^{i^{\frac{\nu-1}{\nu}}}_t\}^{\frac{\nu\alpha}{\nu-1}} L^{i^{1-\alpha}}_{T,t} \tag{73}$$

$$W^i_{T,t} = (1-\alpha) mc^i_{T,t} \frac{v^{p,i}_{T,t} Y^i_{i,t}}{L^i_{T,t}} \tag{74}$$

$$R_{t-1}^{i} = \frac{1}{Q_{T,t-1}^{i}}\{(1-\delta)Q_{T,t}^{i} + \alpha(1-a)mc_{T,t}^{i}K_{T,t}^{i^{-\frac{1}{\nu}}}\frac{v_{T,t}^{p,i}Y_{i,t}^{i}}{(1-a)K_{T,t}^{i^{\frac{\nu-1}{\nu}}} + ax_{t}^{i^{\frac{\nu-1}{\nu}}}}\} \tag{75}$$

$$p_{X,t}^{i} = a\alpha mc_{T,t}^{i}x_{t}^{i^{-\frac{1}{\nu}}}\frac{v_{T,t}^{p,i}Y_{i,t}^{i}}{(1-a)K_{T,t}^{i^{\frac{\nu-1}{\nu}}} + ax_{t}^{i^{\frac{\nu-1}{\nu}}}} \tag{76}$$

$$x_{i,t}^{i} = (1-\gamma)x_{t}^{i}, \;\; i \in \{A, B\} \tag{77}$$

$$x_{C,t}^{C} = x_{t}^{C} \tag{78}$$

$$x_{C,t}^{i} = \gamma x_{t}^{i}, \;\; i \in \{A, B\} \tag{79}$$

$$v_{T,t}^{p,i} = (1-\theta)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\Delta_{1,T,t}^{i}}{p_{i,t}^{i}\Delta_{2,T,t}^{i}}\right]^{-\varepsilon} + \theta v_{T,t-1}^{p,i}\pi_{i,t}^{i^{\varepsilon}} \tag{80}$$

$$\pi_{i,t}^{i^{1-\varepsilon}} = (1-\theta)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\pi_{i,t}^{i}}{p_{i,t}^{i}}\frac{\Delta_{1,T,t}^{i}}{\Delta_{2,T,t}^{i}}\right]^{1-\varepsilon} + \theta \tag{81}$$

$$\Delta_{1,T,t}^{i} = \lambda_{t}^{i}Y_{i,t}^{i}mc_{T,t}^{i} + \beta\theta\mathbb{E}_{t}\left[\Delta_{1,T,t+1}^{i}\pi_{i,t+1}^{i^{\varepsilon}}\right] \tag{82}$$

$$\Delta_{2,T,t}^{i} = \lambda_{t}^{i}Y_{i,t}^{i} + \beta\theta\mathbb{E}_{t}\left[\Delta_{2,T,t+1}^{i}\frac{\pi_{i,t+1}^{i^{\varepsilon}}}{\pi_{t+1}^{i}}\right] \tag{83}$$

$$\pi_{i,t}^{i} = \pi_{t}^{i}\frac{p_{i,t}^{i}}{p_{i,t-1}^{i}} \tag{84}$$

- Commodity intermediate good producing firms' optimality conditions and price setting

$$Y_{X,t}^{i}v_{X,t}^{p,i} = A_{X,t}^{i}K_{X,t}^{i^{\alpha_X}}L_{X,t}^{i^{1-\alpha_X}} \tag{85}$$

$$W_{X,t}^{i} = (1-\alpha_X)mc_{X,t}^{i}\frac{v_{X,t}^{p,i}Y_{X,t}^{i}}{L_{X,t}^{i}} \tag{86}$$

$$R_{t-1}^{i} = \frac{1}{Q_{X,t-1}^{i}}\{(1-\delta)Q_{X,t}^{i} + \alpha_X mc_{X,t}^{i}\frac{v_{X,t}^{p,i}Y_{X,t}^{i}}{K_{X,t}^{i}}\} \tag{87}$$

$$\pi_{X,i,t}^{i^{1-\varepsilon}} = (1-\theta)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\pi_{X,i,t}^{i}}{p_{X,i,t}^{i}}\frac{\Delta_{1,X,t}^{i}}{\Delta_{2,X,t}^{i}}\right]^{1-\varepsilon} + \theta \tag{88}$$

$$v_{X,t}^{p,i} = (1-\theta)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\Delta_{1,X,t}^{i}}{p_{X,i,t}^{i}\Delta_{2,X,t}^{i}}\right]^{-\varepsilon} + \theta v_{X,t-1}^{p,i}\pi_{X,i,t}^{i^{\varepsilon}} \tag{89}$$

$$\Delta^i_{1,X,t} = \lambda^i_t Y^i_{X,t} mc^i_{X,t} + \beta\theta \mathbb{E}_t \left[\Delta^i_{1,X,t+1} \pi^{i^\varepsilon}_{X,i,t+1}\right] \tag{90}$$

$$\Delta^i_{2,X,t} = \lambda^i_t Y^i_{X,t} + \beta\theta \mathbb{E}_t \left[\Delta^i_{2,X,t+1} \frac{\pi^{i^\varepsilon}_{X,i,t+1}}{\pi^i_{t+1}}\right] \tag{91}$$

$$\pi^i_{X,i,t} = \pi^i_t \frac{p^i_{X,i,t}}{p^i_{X,i,t-1}} \tag{92}$$

- Laws of motion for capital

$$K^i_{N,t+1} = \left[1 - \frac{\xi}{2}\left(\frac{I^i_{N,t}}{I^i_{N,t-1}} - 1\right)^2\right] I^i_{N,t} + (1-\delta) K^i_{N,t} \tag{93}$$

$$K^i_{T,t+1} = \left[1 - \frac{\xi}{2}\left(\frac{I^i_{T,t}}{I^i_{T,t-1}} - 1\right)^2\right] I^i_{T,t} + (1-\delta) K^i_{T,t} \tag{94}$$

$$K^i_{X,t+1} = \left[1 - \frac{\xi}{2}\left(\frac{I^i_{X,t}}{I^i_{X,t-1}} - 1\right)^2\right] I^i_{X,t} + (1-\delta) K^i_{X,t} \tag{95}$$

- Optimal investment

$$\begin{aligned} p^i_{N,t} = Q^i_{N,t} \left[1 - \frac{\xi}{2}\left(\frac{I^i_{N,t}}{I^i_{N,t-1}} - 1\right)^2\right] - \xi Q^i_{N,t} \frac{I^i_{N,t}}{I^i_{N,t-1}} \left(\frac{I^i_{N,t}}{I^i_{N,t-1}} - 1\right) \\ + \beta\xi \mathbb{E}_t \left[\frac{\lambda^i_{t+1}}{\lambda^i_t} \frac{I^{i2}_{N,t+1}}{I^{i2}_{N,t}} \left(\frac{I^i_{N,t+1}}{I^i_{N,t}} - 1\right) Q^i_{N,t+1}\right] \end{aligned} \tag{96}$$

$$\begin{aligned} p^i_{i,t} = Q^i_{T,t} \left[1 - \frac{\xi}{2}\left(\frac{I^i_{T,t}}{I^i_{T,t-1}} - 1\right)^2\right] - \xi Q^i_{T,t} \frac{I^i_{T,t}}{I^i_{T,t-1}} \left(\frac{I^i_{T,t}}{I^i_{T,t-1}} - 1\right) \\ + \beta\xi \mathbb{E}_t \left[\frac{\lambda^i_{t+1}}{\lambda^i_t} \frac{I^{i2}_{T,t+1}}{I^{i2}_{T,t}} \left(\frac{I^i_{T,t+1}}{I^i_{T,t}} - 1\right) Q^i_{T,t+1}\right] \end{aligned} \tag{97}$$

$$\begin{aligned} p^i_{X,i,t} = Q^i_{X,t} \left[1 - \frac{\xi}{2}\left(\frac{I^i_{X,t}}{I^i_{X,t-1}} - 1\right)^2\right] - \xi Q^i_{X,t} \frac{I^i_{X,t}}{I^i_{X,t-1}} \left(\frac{I^i_{X,t}}{I^i_{X,t-1}} - 1\right) \\ + \beta\xi \mathbb{E}_t \left[\frac{\lambda^i_{t+1}}{\lambda^i_t} \frac{I^{i2}_{X,t+1}}{I^{i2}_{X,t}} \left(\frac{I^i_{X,t+1}}{I^i_{X,t}} - 1\right) Q^i_{X,t+1}\right] \end{aligned} \tag{98}$$

- Resource constraints

$$Y^i_{N,t} = C^i_{N,t} + I^i_{N,t} \tag{99}$$

$$Y^i_{i,t} = C^i_{i,t} + C^l_{i,t} + C^m_{i,t} + I^i_{T,t}, \;\; l \neq i, \;\; m \neq i, l \tag{100}$$

$$Y^i_{X,t} = C^i_{X,i,t} + x^i_{i,t} + I^i_{X,t}, \;\; i \in \{A, B\} \tag{101}$$

$$Y^C_{X,t} = C^A_{X,C,t} + C^B_{X,C,t} + C^C_{X,t} + x^A_{C,t} + x^B_{C,t} + x^C_t + I^C_{X,t} \tag{102}$$

- Monetary policy and Fisher equations

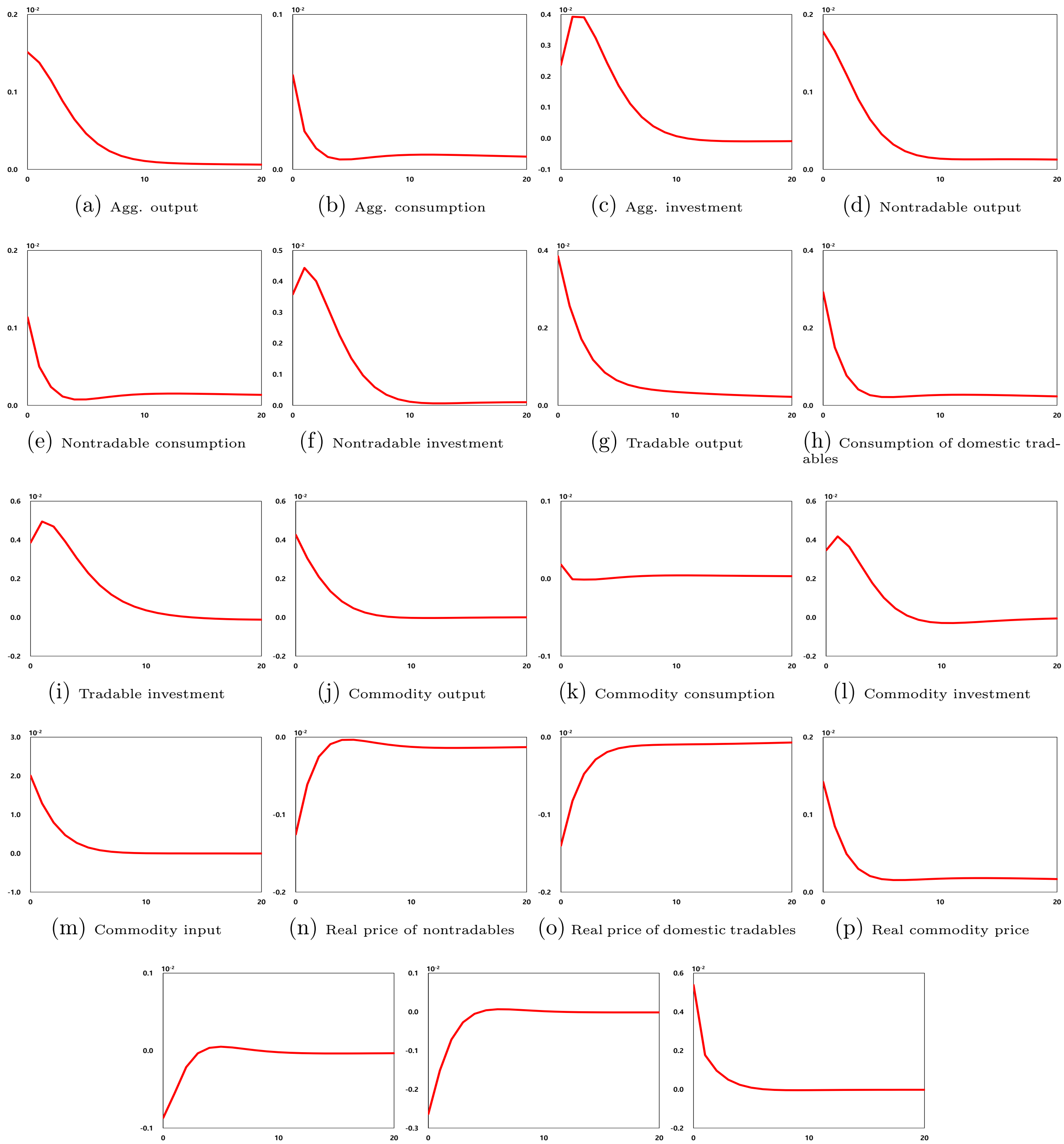
$$i^i_t = \rho_I i^i_{t-1} + (1 - \rho_I)\{\phi_\pi(\pi^i_t - \pi^i) + \phi_Y(\ln Y^i_t - \ln Y^i)\} + v^i_t \tag{103}$$

$$R^i_t = \mathbb{E}_t \left[i^i_t / \pi^i_{t+1} \right] \tag{104}$$

with $\ln v^i_t = \rho \ln v^i_{t-1} + u^i_t$.

C. Responses of the model

Country A (the U.S.)



(a) Agg. output (b) Agg. consumption (c) Agg. investment (d) Nontradable output

(e) Nontradable consumption (f) Nontradable investment (g) Tradable output (h) Consumption of domestic tradables

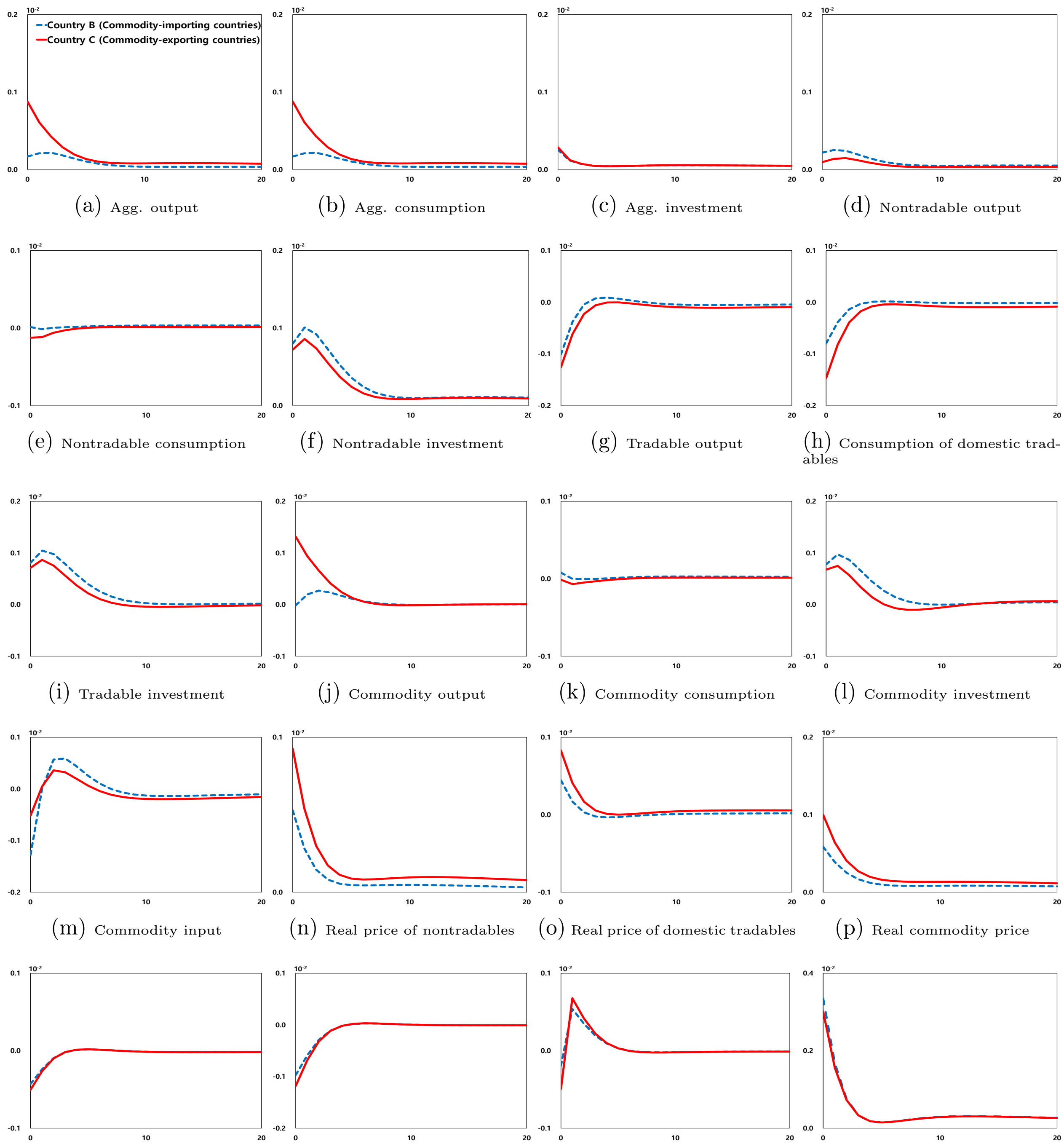
(i) Tradable investment (j) Commodity output (k) Commodity consumption (l) Commodity investment

(m) Commodity input (n) Real price of nontradables (o) Real price of domestic tradables (p) Real commodity price

(q) Nominal interest rate (r) Real interest rate (s) CPI inflation

Figure 7: Responses of country A to an expansionary monetary policy shock to country A

Countries B (commodity importers) and C (commodity exporters)



(a) Agg. output (b) Agg. consumption (c) Agg. investment (d) Nontradable output

(e) Nontradable consumption (f) Nontradable investment (g) Tradable output (h) Consumption of domestic tradables

(i) Tradable investment (j) Commodity output (k) Commodity consumption (l) Commodity investment

(m) Commodity input (n) Real price of nontradables (o) Real price of domestic tradables (p) Real commodity price

(q) Nominal interest rate (r) Real interest rate (s) CPI inflation (t) Real exchange rate

Figure 8: Responses of countries B and C to an expansionary monetary policy shock to country A

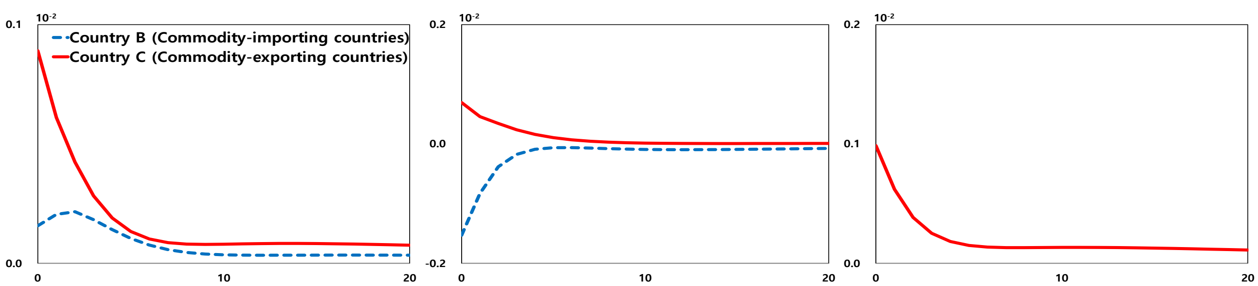
D. Sensitivity analysis

In this section, I test whether the main results of the model are sensitive to changes in the values of parameters that are new due to the introduction of commodities. Specifically, I check whether in response to an expansionary U.S. monetary policy shock, the real commodity price increases and exports and aggregate output of commodity-exporting countries rise by more than those of commodity-importing countries when the values of the depreciation rate of capital for the commodity production, the elasticity of substitution between capital and commodities in the tradable production, the labour share of income in the commodity sector, the weight of commodity consumption goods in the composite of consumption goods, and the elasticity of substitution between commodity and noncommodity consumption goods are different from the parameterisation values in Section 4.

Depreciation rate of capital for the commodity production (δ_X)

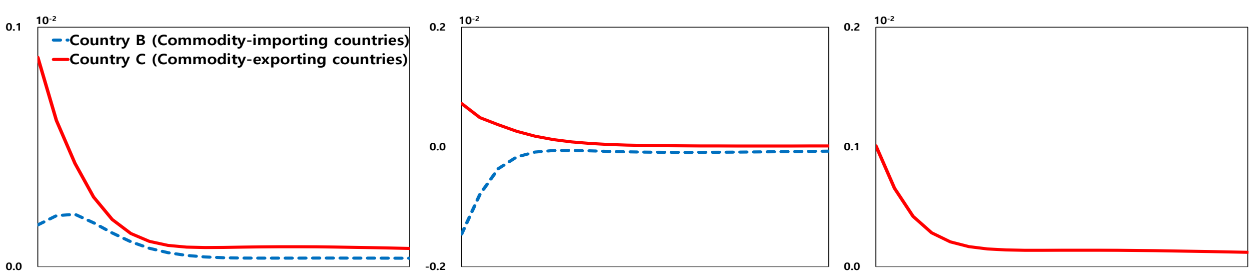
Figure 9 shows that the main results of the model hold when $\delta_X = 0.02$ and $\delta_X = 0.03$.

$<\delta_X = 0.02>$



(a) Agg. output (b) Exports (c) Real commodity price in C

$<\delta_X = 0.03>$



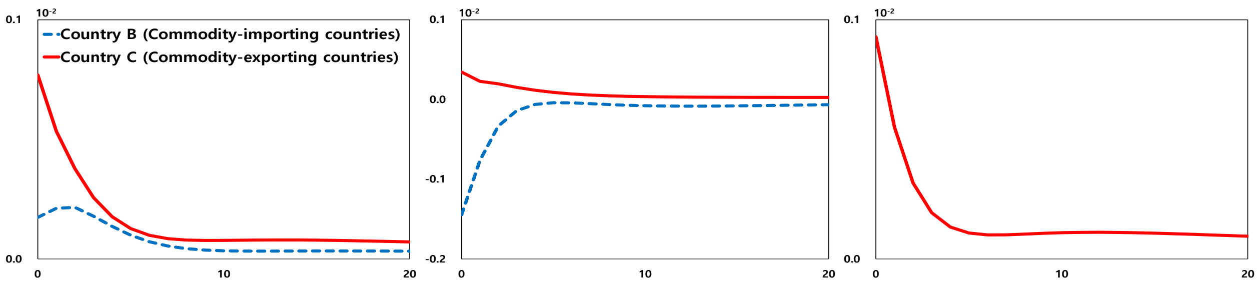
(d) Agg. output (e) Exports (f) Real commodity price in C

Figure 9: Responses to an expansionary monetary policy shock to country A

Elasticity of substitution between capital and commodities in the tradable production (ν)

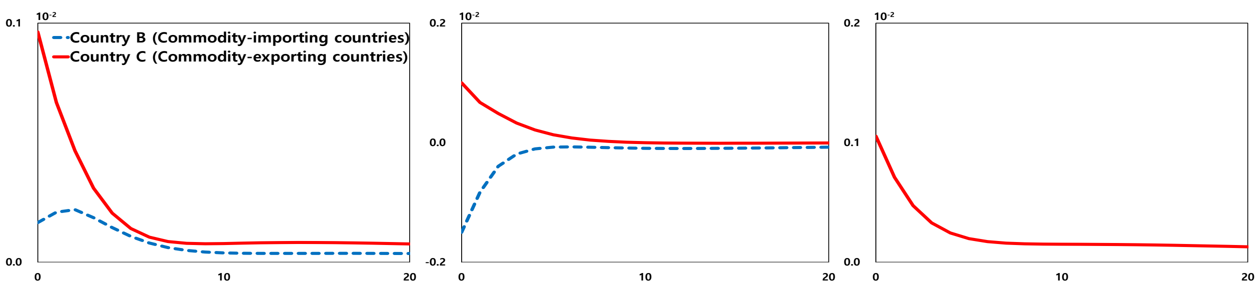
Figure 10 shows the responses of the model to an expansionary monetary policy shock to country A, when $\nu = 0.5$ and $\nu = 1.5$. In both cases, the main results of the model hold.

$$<\nu = 0.5>$$



(a) Agg. output (b) Exports (c) Real commodity price in C

$$<\nu = 1.5>$$



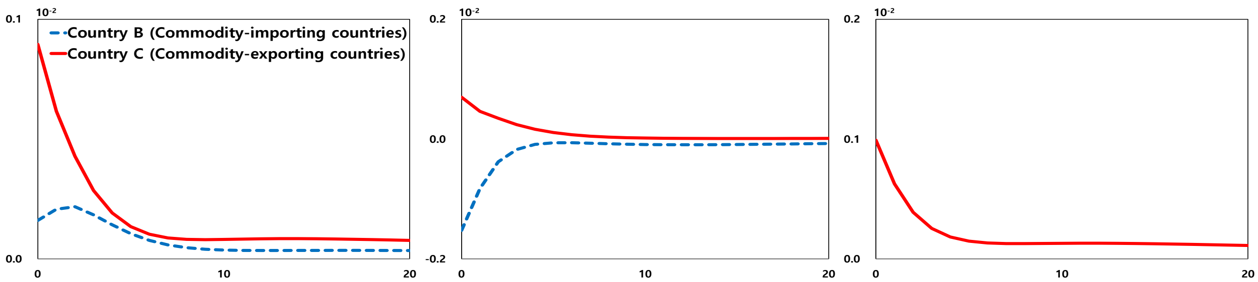
(d) Agg. output (e) Exports (f) Real commodity price in C

Figure 10: Responses to an expansionary monetary policy shock to country A

Labour share of income in the commodity sector $(1-\alpha_X)$

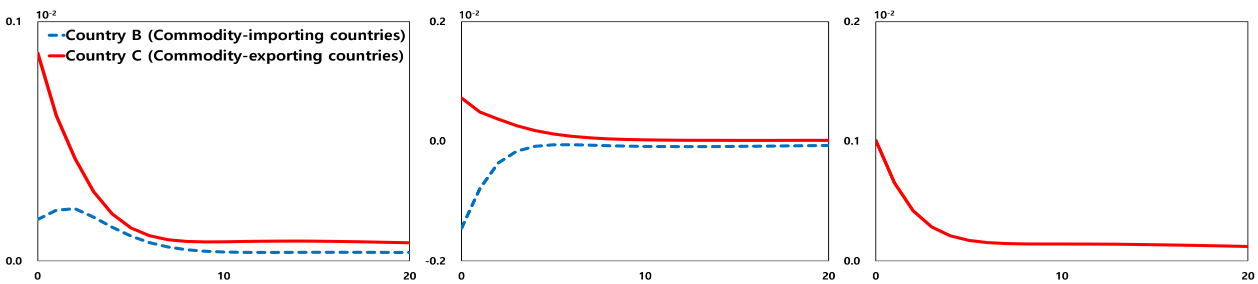
Figure 11 shows that the main results of the model are maintained, when $1-\alpha_X = 0.64$ and $1-\alpha_X = 0.68$.

$$<1-\alpha_X = 0.64>$$



(a) Agg. output (b) Exports (c) Real commodity price in C

$$<1-\alpha_X = 0.68>$$



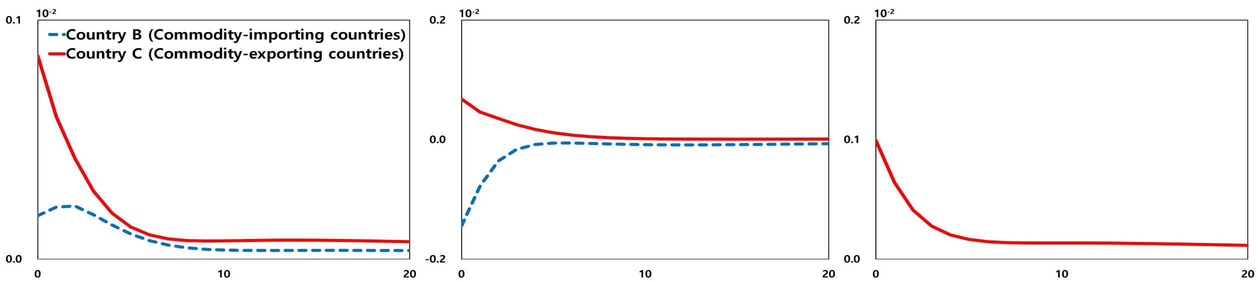
(d) Agg. output (e) Exports (f) Real commodity price in C

Figure 11: Responses to an expansionary monetary policy shock to country A

Weight of commodity consumption goods in the composite of consumption goods (γ_0)

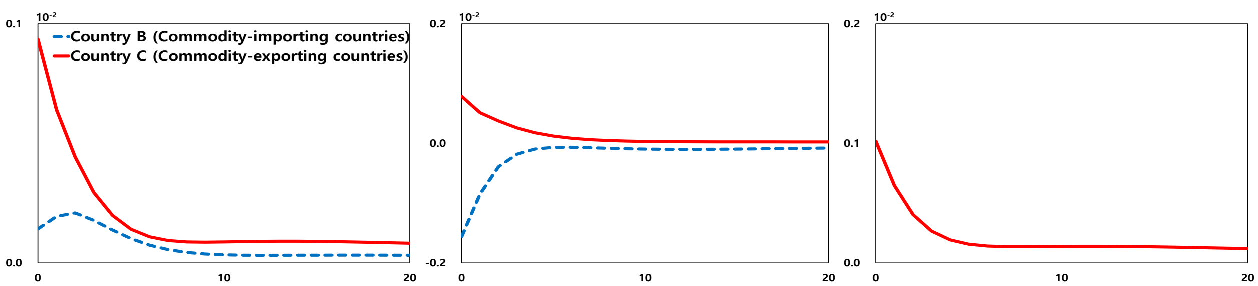
Figure 12 gives the responses of the model to an expansionary monetary policy shock to country A when $\gamma_0 = 0.1$ and $\gamma_0 = 0.13$. In both cases, the shock has stronger effects on commodity-exporting countries than on commodity-importing countries.

$<\gamma_0 = 0.1>$



(a) Agg. output (b) Exports (c) Real commodity price in C

$<\gamma_0 = 0.13>$



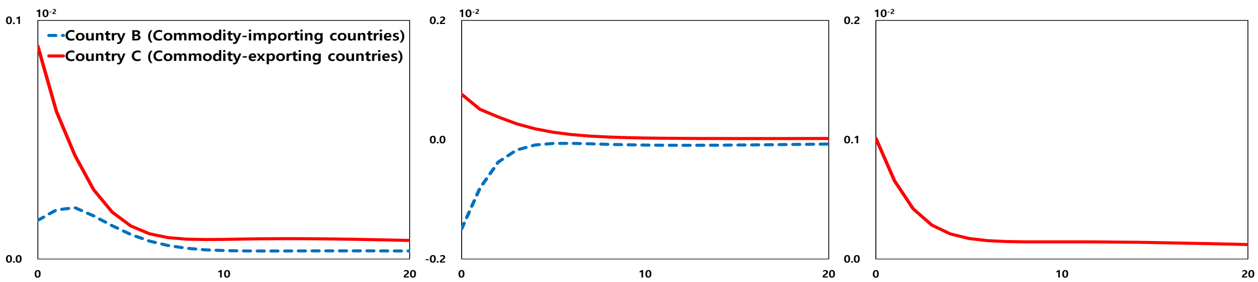
(d) Agg. output (e) Exports (f) Real commodity price in C

Figure 12: Responses to an expansionary monetary policy shock to country A

Elasticity of substitution between commodity and noncommodity consumption goods (η_0)

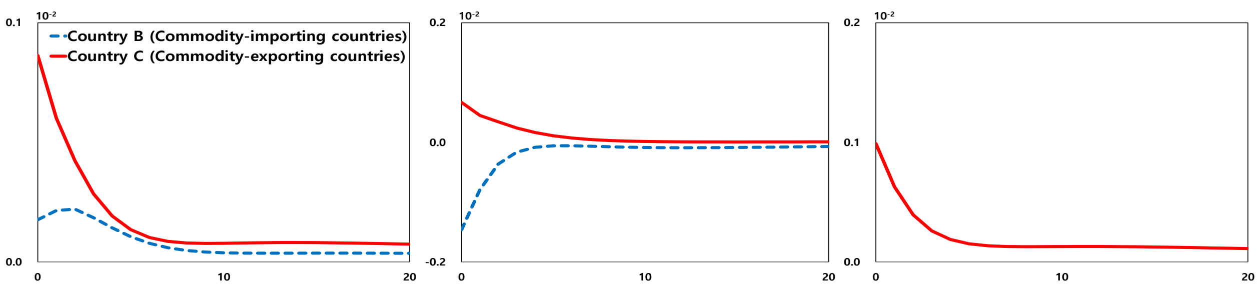
Figure 13 presents the responses of the model to an expansionary monetary policy shock to country A when $\eta_0 = 0.1$ and $\eta_0 = 0.5$. Under the two values of η_0, the main results of the model are maintained.

$<\eta_0 = 0.1>$



(a) Agg. output (b) Exports (c) Real commodity price in C

$<\eta_0 = 0.5>$



(d) Agg. output (e) Exports (f) Real commodity price in C

Figure 13: Responses to an expansionary monetary policy shock to country A

Conclusion

This thesis introduces commodities into otherwise standard macro models, and considers different commodity trade structures of countries in open economy macro models. Commodities are shown to be a useful addition to these models, since they help to explain the recently declined effects of commodity price shocks on the economy, international business cycles between the U.S. and commodity-exporting countries, and international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries.

Chapter 1 investigates whether commodities as an asset class have contributed to the recent reduction in the impacts of commodity price shocks on the economy by extending a standard model with financial frictions so that financial intermediaries invest in commodities as well as capital. The simulation results of the model show that commodities as an asset class have played an important role in the recently reduced impacts of commodity price shocks on the economy. In the model a negative commodity price shock causes not only a rise in the return to financial intermediaries' investment in capital but also a fall in the return to their investment in commodities. Therefore, the net worth of financial intermediaries increases by less than that in a model in which financial intermediaries do not invest in commodities. As a consequence, financial intermediaries' investment in shares in capital issued by firms goes up by less, which causes smaller responses of investment and output to the shock.

Chapter 2 analyses international business cycles between the U.S. and commodity-exporting countries. It first shows that international business cycles between the U.S. and commodity-exporting countries are significantly different from those between the U.S. and commodity-importing countries. Then, it demonstrates that the two-country model in the chapter in which commodities and different commodity trade structures of countries are considered generates closer international business cycle statistics to the data compared to a standard two-country model. The model produces higher output correlation and lower consumption correlation than the standard model. Moreover, the model yields output correlation that is higher than the consumption correlation, which is consistent with the ranking in the data. Specifically, the complementarity between commodity and noncommodity goods in consumption enables the output correlation to be greater. As for the consumption correlation, the negatively correlated home and foreign commodity consumptions with respect to productivity shocks to the nontradable sector help the correlation between home and foreign commodity consumptions to be lower than that between home and foreign noncommodity consumptions, and hence the consumption correlation in the model is smaller than that in the standard model.

Chapter 3 constructs a three-country model in which commodities and different commodity trade structures are included to study international transmission of U.S. monetary policy shocks to commodity-exporting and commodity-importing countries. By using an econometric methodology, the chapter first shows empirically that an expansionary U.S. monetary policy shock increases output of commodity-exporting countries by more than that of commodity-importing countries, since in response to the shock commodity prices rise and exports of the former go up by more than those of the latter. Then, the chapter shows that the three-country model captures the empirical mechanism well. Specifically, an expansionary U.S. monetary policy raises its demand for commodities and thus commodity prices. Accordingly, commodity exports of commodity-exporting countries to the U.S. go up, which causes a bigger rise in exports of commodity-exporting countries than those of commodity-importing countries. As a result, aggregate output of commodity-exporting countries increases by more compared to that of commodity-importing countries.

Although this thesis shows that adding commodities with consideration for different commodity trade structures to standard macro models is very useful, there is still room for improvement.

In Chapter 1, it is assumed that financial intermediaries invest a fixed portion of their expenditure on investment in commodities. However, if financial intermediaries' investment is endogenous, i.e. they choose investments in commodities and capital in each period according to the commodity and capital returns, richer analysis may be possible. Nevertheless, I leave this for future research, since the aim of the chapter is to show that as long as financial intermediaries invest some amount in commodities the impacts of commodity price shocks on the economy become weaker, rather than to analyse how financial intermediaries allocate available funds to the two assets.

The open economy macro models in Chapters 2 and 3 do not consider investment goods as a composite of goods of every sector, the distribution sector and the price elasticity of commodity supply. Considering these in open economy macro models would be interesting future research.

With regard to investment goods, suppose that producing investment goods in each sector requires home and foreign tradable goods, nontradable goods, and commodities, rather than the sector's own goods as in Chapter 2. Then, the results of the chapter will be different. Nevertheless, the differences will be marginal. When positive productivity shocks hit the home country, its demand for foreign tradable goods and commodities will increase by more than the model in the chapter, since producing investment goods in the home tradable and nontradable sectors also requires foreign tradable goods and commodities, and thus their real prices will go up by more. Despite a larger increase in home demand for foreign tradable goods and commodities, increases in outputs in the foreign tradable and commodity sectors will be similar to those in the model in the chapter due to bigger increases in their real prices. Therefore, the output correlation will also be similar, even though investment goods are considered as a composite of goods of every sector. As for the consumption correlation, positive productivity shocks to the home country will increase the real prices of foreign tradable goods and commodities by more, which will cause a bigger fall in the real price of foreign nontradable goods. The larger increases in the real prices of foreign tradable goods and commodities will lead to smaller rises in their foreign consumptions, but the larger fall in the real price of foreign nontradable goods will bring about a bigger increase in the foreign nontradable consumption. Therefore, the rise in the foreign aggregate consumption will be similar to that in the model in the chapter. As a result, the consumption correlation will not be notably different from that in the model in Chapter 2, even if investment goods are a composite of goods of each sector.

Now suppose that there is a distribution sector in Chapter 2, and let consuming a unit of tradable or commodity goods require certain units of nontradable goods. As already seen in the chapter, a positive productivity shock to the home tradable sector increases foreign tradable and commodity consumptions. If the distribution sector is present, foreign nontradable consumption will increase by more than that in the model in the chapter, which will lead to a larger rise in output in the foreign nontradable sector compared to the model in the chapter. Therefore, foreign aggregate output and consumption will go up by more. As a consequence, the output and consumption correlations will become higher with respect to productivity shocks to the tradable sector. However, these two correlations will become lower with respect to productivity shocks to the nontradable sector. To explain, a positive productivity shock in the home nontradable sector leads to falls in foreign tradable and commodity consumptions as seen in the chapter. The presence of the distribution sector will lead to a larger fall in foreign nontradable consumption compared to the model in the chapter, and thus output in the foreign nontradable sector will decrease by more. Hence, foreign aggregate output will rise by less, and foreign aggregate consumption will fall by more. As a result, the output and consumption correlations with respect to productivity shocks to the nontradable sector will be lower than those in the model in the chapter. Putting these effects together, since the effects of the presence of the distribution sector on the output and consumption correlations with respect to productivity shocks to the tradable and nontradable sectors will be opposite, the overall effect is ambiguous.

Consider the price elasticity of commodity supply which is generally known to be inelastic in the short run and elastic in the long run, as applied to the model in Chapter 3. If commodity supply is price inelastic (elastic), in response to a rise in the real commodity price due to an increase in U.S. demand for commodities triggered by an expansionary U.S. monetary policy shock, the commodity output of commodity-exporting countries will increase by less (more) than the model in the chapter. Therefore, the supply of commodities will be too low (high) compared to the increased demand, which will cause a larger (smaller) increase in the real commodity price than the model in the chapter. The smaller (larger) increase in the commodity output of commodity-exporting countries will reduce (increase) the positive effects of the shock on commodity-exporting countries, but the larger (smaller) increase in the real commodity price will increase (reduce) the positive impacts of the shock on commodity-exporting countries. Therefore, it is ambiguous whether U.S. monetary policy shocks will have stronger or weaker spillovers to commodity-exporting countries compared to the model in the chapter.

Although considering these elements in the models in this thesis would be interesting, I leave formal checks of these hypotheses for future research.