How the Financial Market Can Dampen the Effects of Commodity Price Shocks*

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Abstract

Commodities have begun to function as an asset class during the past decade, as trading in commodity derivatives has increased massively since the mid-2000s. This paper studies the role of commodities as an asset class in accounting for the recently lessened impacts of commodity price shocks on the economy, by constructing a model with a financial accelerator and with financial intermediaries that own two assets – tied to commodities as well as to capital. Simulation results of the model show that financial intermediaries' holdings of commodities as assets have contributed to the recent reduction in the effects of commodity price shocks.

1. Introduction

It is generally accepted that there is an inverse relationship between the prices of commodities such as oil, wheat, basic metals, etc. and the economy: when commodity prices fall, the economic effects of this are positive. This is because a fall in commodity prices leads to a decrease in living costs and an increase in real income. Moreover, when commodity prices fall, firms using commodities as inputs benefit from the low input prices.

Many studies have confirmed this inverse relationship between commodity prices (especially oil prices) and the economy. Hamilton (1983) presents evidence supporting the proposition that oil price shocks contributed to almost every U.S. recession over the 1948-72 period. Burbidge and Harrison (1984), Rotemberg and Woodford (1996), Cuñado and

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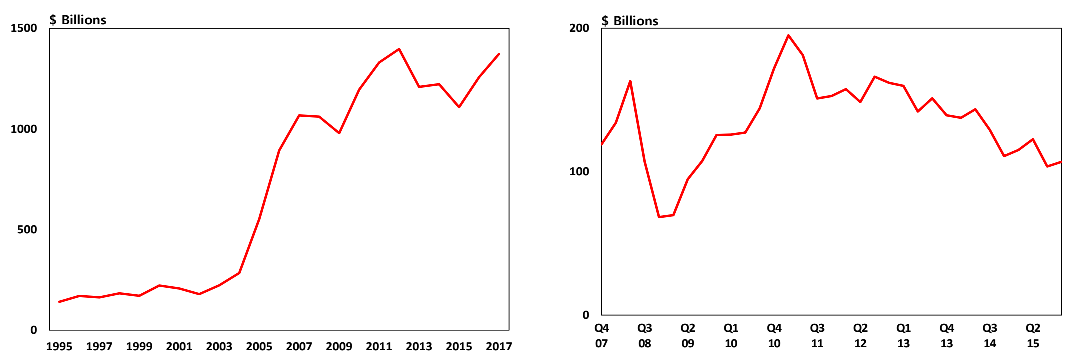
de Gracia (2003) and Leduc and Sill (2004) also show that an increase in oil prices brings about declines in industrial production or in output.

However, there is other literature providing evidence that energy price shocks have little effect on the economy. For example, Kim and Loungani (1992) include energy in a real business cycle (RBC) model with exogenous energy prices and find that the inclusion of energy price shocks increases output volatility only modestly. Dhawan and Jeske (2008) obtain similar results by extending the model of Kim and Loungani (1992). Krugman (2016) also argues that the assumed relationship does not hold, since for example spending for investment falls quickly when oil prices plunge, as a lot of it is tied to oil prices.

More importantly, according to some literature, when more recent data is used the relationship between commodity prices and macroeconomic variables is found to be insignificant or attenuated. Using vector autoregressions (VARs) over the 1970-83 and 1984-2006 periods, Blanchard and Galí (2010) conclude that oil prices had a much lower impact on inflation and output in the second period than they did in the first. According to them, this was due to the lack of concurrent adverse shocks, the smaller share of oil in the economy, more flexible labor markets and improvements in monetary policy during the second period. Segal (2011) and Katayama (2013) also find that the rises in oil prices during the last few years have had little influence on the economy.[1]



(a) Notional value of contracts

(b) Notional value of net long position

Figure 1: Commodity derivative contracts

Notes: The values in (a) are the year-end notional amounts of commodity derivative contracts for commercial banks, savings associations and trust companies holding derivatives in the U.S. The values in (b) are the quarter-end notional amounts in the U.S. futures market including index investment greater than or equal to 0.5 billion U.S. dollars.
Sources: Quarterly Report on Bank Trading and Derivatives Activities, Office of the Comptroller of the Currency, U.S. Department of the Treasury and U.S. Commodity Futures Trading Commission

Something that is not discussed in the above literatures is the fact that trading in commodity derivatives tied to commodity prices has increased massively since the mid-2000s[2] (see

[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 they were due to strong demand for oil thanks to the booming world economy rather than to oil supply disruptions.

[2] Basu and Gavin (2011) explain well why many financial intermediaries have added commodity derivatives as an asset class to their portfolios. The first reason is the search for higher yields; when the returns on safe

(a) in Figure 1). Moreover, the value of net long position of commodity derivative contracts in the U.S. futures market have been positive (see (b) in Figure 1).[3] As a result, commodities have in recent years begun to function as an asset class, which may have contributed to the aforementioned weakened relationship as well.

Specifically, suppose that firms produce goods by using commodities, capital and labor as inputs, and financial intermediaries (FIs) own two assets – one tied to the capital of firms and the other to commodities. The net worths of FIs will then be affected by the returns on capital and commodities, both of which depend on changes in commodity prices. For instance, a fall in commodity prices will reduce firms' input costs and their outputs will hence rise, which will lead to an increased return on capital. In contrast, the commodity price decline will lead directly to a decreased return on commodities as well. Under this environment, if commodity prices decrease the net worths of FIs will rise by less than in a case in which they hold only capital. This will lead to a smaller increase in FIs' demand for investment, which will partly offset the positive impact of the fall in commodity prices on the economy.

However, it is impossible to capture the linkage between commodity prices and the net worths of FIs or FI profitability with the existing models in which financial markets are modeled, since these models omit the role of commodities as an asset class. For example, Bernanke, Gertler and Gilchrist (1999, hereafter BGG) assume that entrepreneurs borrow money from FIs to purchase capital and are leveraged. In their model, owing 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). Similarly, other studies also do not consider commodities as an asset class, and in their models FIs or entrepreneurs hold only assets tied to capital (see Gertler and Karadi, 2011; Christiano, Motto and Rostagno, 2014; etc.). There are also models that do contain two assets for FIs or entrepreneurs, but they mainly extend the framework of BGG to two-country models and the two assets are thus capital at home and capital in foreign countries (see Ueda, 2012; and Dedola and Lombardo, 2012). In any case, the existing models consider FIs or entrepreneurs to hold only assets tied to capital.

This paper begins by providing empirical evidence that the influences of commodity prices on U.S. economy have declined since the mid-2000s and their impacts on FI profitability have become stronger. Using a VAR, I show that the responses of U.S. macroeconomic variables to a negative commodity price shock are statistically significant during the pre-2005 period but mostly insignificant during the post-2005 period. I then present estimation results that

assets are low, intermediaries tend to choose riskier assets. Second, they use commodity derivatives to hedge against equity risks in line with the negative correlation between equity and commodity returns.

[3] The data from the U.S. Commodity Futures Trading Commission is only available for the December 2007-October 2015 period.

during the latter period commodity prices have significant effects on FI profitability but not during the former period.

Building on the empirical evidence, I extend the model with the financial accelerator developed by BGG, by adding to it FIs that invest in assets tied to both commodities and capital. I use this model to show that if FIs can hold two assets, tied to commodities as well as to the capital of firms, then the effects of a negative commodity price shock on the economy will be attenuated. The simulation results of the model reveal that the responses of macroeconomic variables to a negative commodity price shock are weaker than those in a model without FIs' investment in commodities. Based on these results, I conclude that commodities as an asset class play a role in the reduced impacts of commodity price shocks.

The remainder of the paper is organized as follows. Section 2 provides the empirical evidence that the impacts of commodity prices on the U.S. economy have been reduced and their effects on FI profitability have strengthened since the mid-2000s. Section 3 describes the model, in which FIs invest in two assets – tied both to capital and to commodities. Section 4 presents the simulation results of the model, and explains why its inclusion of commodities as an asset class is important and relevant. Section 5 concludes.

2. Empirical Evidence

In this section, I first provide evidence that the effects of commodity price shocks on U.S. output have been attenuated since the mid-2000s when trading of commodity derivatives increased rapidly by using a VAR. Then I show that the impacts of commodity prices on FI profitability have been stronger since the mid-2000s.

2.1. Declining Effects of Commodity Price Shocks

In order to show that the influences of commodity price shocks on the U.S. economy have weakened since 2005, I estimate a six-variable VAR. Following Katayama (2013), I use the net commodity price increase for a measure of commodity price shocks to capture exogenous fluctuations in commodity prices instead of the log changes in the commodity price index which are used in Blanchard and Galí (2010).[4] As defined by Hamilton (1996), the net commodity price increase compares commodity prices in the current quarter with their peak value during the previous four quarters. That is, if current prices are higher than the previous peak, it is the percentage change over the peak; otherwise, it is zero.

As in Blanchard and Galí (2010), the other five variables in the VAR are the CPI inflation,

[4] I also estimate the VAR by using the log changes in the commodity price index for a measure of commodity price shocks as in Blanchard and Galí (2010). However, there are no notable differences in the two estimation results.

GDP deflator inflation, wage growth, GDP growth and employment.[5] To identify the VAR, I use a standard Cholesky decomposition, and the order of the six variables are listed as above.[6] Since the commodity price index of the IMF starts from 1992, I use the World Bank's energy and non-energy price indices, which are available from 1960, and 0.631 for the weight of energy price index, which is used in the IMF's commodity price index, to construct the commodity price index. The source of the other five variables is the Federal Reserve Economic Data (FRED) of the St. Louis Fed. The lag length of the VAR is four quarters, and a constant term and a quadratic time trend for the measure of productivity growth are included in the VAR.

Finally, to examine whether the effects of commodity price shocks have changed since the mid-2000s when commodities began to function as an asset class, I divide the full sample period (Q2 1960-Q2 2018) into two: Q2 1960 to Q4 2004 and Q1 2005 to Q2 2018.[7]

The responses of variables in the VAR to a 10% decrease in the net commodity price increase in the two sample periods are presented in Figure 2. For the pre-2005 subsample, responses of all variables to the shock are statistically significant. To be specific, CPI inflation, GDP deflator inflation and wage inflation fall, whereas GDP growth and employment growth increase. In contrast, in the post-2005 period the responses of these variables except for CPI inflation are not statistically significant. Although in response to the shock, CPI inflation falls by more than that does in the pre-2005 period, the persistence of the fall is much smaller.

In short, these results provide evidence that the effects of commodity price shocks on the U.S. economy have declined since 2005, as commodities have begun to function as an asset class.

[5] Following Blanchard and Galí (2010), nonfarm business hour growth is used for employment and for the wage I use nonfarm business compensation per hours.

[6] As noted in Blanchard and Galí (2010), if commodity prices are contemporaneously affected by U.S. economic conditions, this identification will be incorrect. Therefore, I also use an alternative ordering of variables when estimating the VAR. Specifically, I let the net commodity price increase react contemporaneously to the GDP growth and employment which do not react to the net commodity price increase contemporaneously. Since the results are almost identical, I do not report.

[7] Considering that the latter period is relatively short, I also estimate two sample periods (Q2 1960 to Q4 1999 and Q1 2000 to Q2 2018). Nonetheless, the estimate results are almost the same as those when splitting the full sample period by Q1 2005.

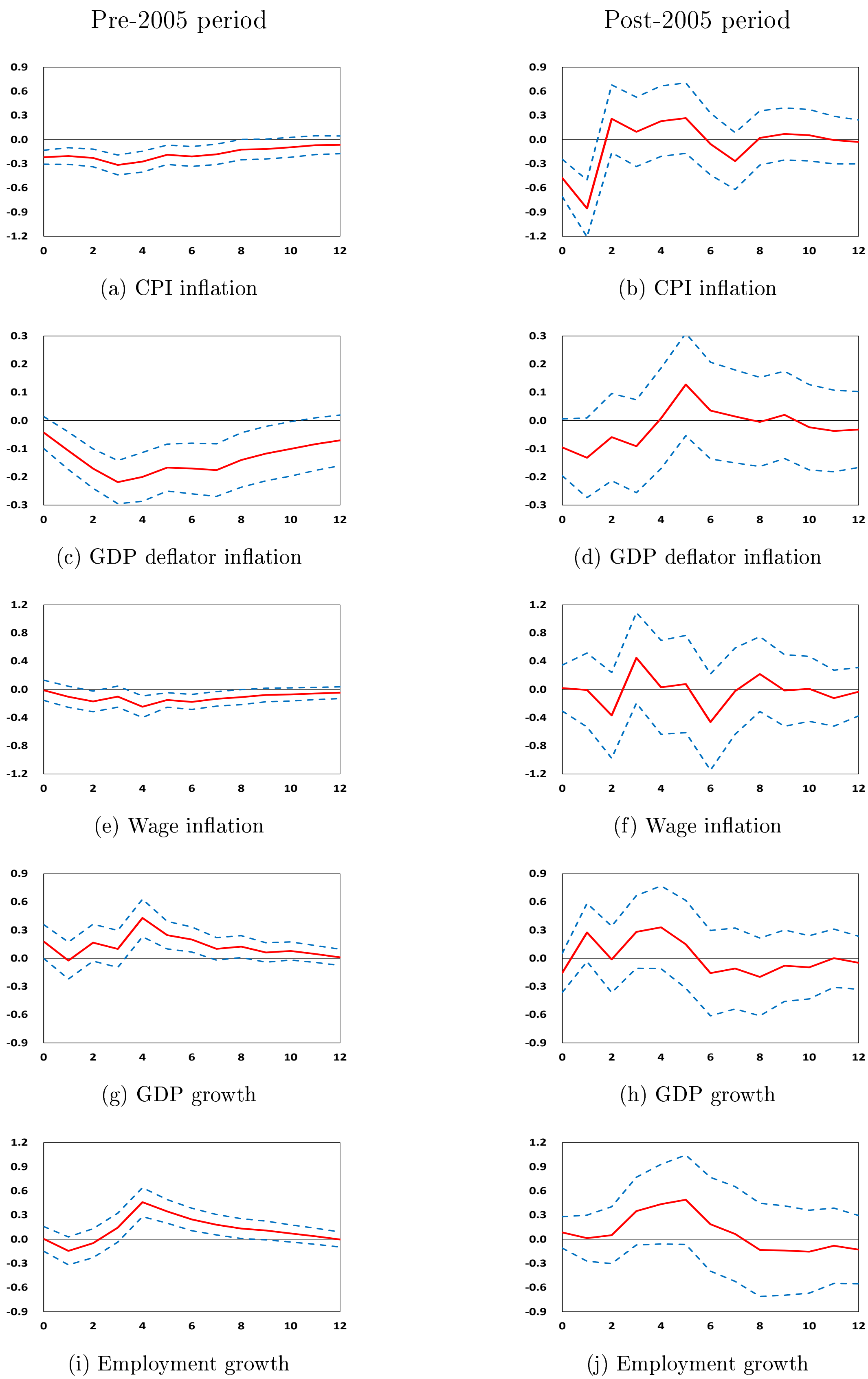


Figure 2: Responses to a negative commodity price shock

Note: The dashed lines are 90% confidence intervals.

2.2. Effects of Commodity Prices on FI Profitability

In this section, I analyze whether the impacts of commodity prices on FI profitability have been stronger since 2005.

Following Borio, Gambacorta and Hofmann (2017), I regress a measure of FI profitability on the net commodity price increase and other macro variables. I use the ratio of net income to total assets (return on assets) for all U.S. commercial banks as a measure of FI profitability. Specifically, the following regression model is estimated.[8]

$$ROA_t = \alpha_0 + \alpha_1 ROA_{t-1} + \sum_{j=0}^{1} \beta_j NCPI_{t-j} + \sum_{j=0}^{1} \gamma_j' X_{t-j} + \varepsilon_t,$$

where ROA is the return on assets and $NCPI$ denotes the net commodity price increase. X is a vector of other macro variables, which include the 3-month Treasury bill rate, slope of the yield curve (difference between the 10-year government bond yield and the 3-month Treasury bill rate), growth rate of GDP, stock index (S&P 500 index) growth rate and growth rate of house price index. Considering the non-linearities in the relationship between the interest rates and ROA shown in Borio, Gambacorta and Hofmann (2017), X includes the quadratic terms of the 3-month Treasury bill rate and slope of the yield curve as well.[9] The net commodity price increase is the same as the previous section and the source of the S&P 500 index is the Bloomberg. The source of the other variables are the FRED. Finally, the full sample period is Q3 1984 to Q2 2018. As in the previous section, to analyze whether commodity prices have become more significant in explaining FI profitability, I consider two sample periods: Q3 1984-Q4 2004 and Q1 2005-Q2 2018.

The estimation results are presented in Table 1.[10] The coefficients of $NCPI_t$ and $NCPI_{t-1}$ (β_0 and β_1) for the period Q3 1984-Q4 2004 are not statistically significant, while the coefficient of $NCPI_{t-1}$ (β_1) for the period Q1 2005-Q2 2018 is statistically significant at 5% level. This clearly shows that the influences of commodity prices on FI profitability have been stronger since 2005.

[8] Since Borio, Gambacorta and Hofmann (2017) use annual data, they do not include lags of control variables. However, I use quarterly data, and thus I include one lag of control variables in the model.

[9] Borio, Gambacorta and Hofmann (2017) include bank specific characteristics such as the size and liquidity, since they exploit bank-level data. However, aggregate data is used in this paper, and thus I include only macro variables as control variables as in Albertazzi and Gambacorta (2009).

[10] The coefficient of the lagged 3-month Treasury bill rate for the period Q1 2005-Q2 2018 is negative and statistically significant, which is in line with the results of Hardy and Pazarbaşioğlu (1999) and Albertazzi and Gambacorta (2009). This is because an increase in short-term rates raises funding costs of banks.

Table 1: Estimation results

	Dependent variable: FI profitability	
Explanatory variables:	Q3 1984-Q4 2004	Q1 2005-Q2 2018
Constant	0.2412***	0.4045***
	(0.0876)	(0.1474)
Lagged dependent variable	0.8236***	0.3249**
	(0.0635)	(0.1206)
3-month Treasury rate	-0.0108	0.2120
	(0.0446)	(0.1459)
Lagged 3-month Treasury rate	-0.0060	-0.4418***
	(0.0369)	(0.1442)
3-month Treasury rate^2	-0.0021	-0.0267
	(0.0024)	(0.0219)
Lagged 3-month Treasury rate^2	0.0021	0.0743***
	(0.0025)	(0.0239)
Slope of the yield curve	-0.0349	-0.0853
	(0.0517)	(0.1113)
Lagged slope of the yield curve	0.0062	0.0896
	(0.0402)	(0.1023)
Slope of the yield curve^2	-0.0060	0.0056
	(0.0093)	(0.0267)
Lagged slope of the yield curve^2	0.0114	-0.0200
	(0.0090)	(0.0270)
GDP growth	0.0317*	-0.0144
	(0.0180)	(0.0319)
Lagged GDP growth	-0.0001	0.0189
	(0.0164)	(0.0366)
Stock index growth	-0.0008	-0.0040
	(0.0011)	(0.0026)
Lagged stock index growth	-0.0028	-0.0021
	(0.0019)	(0.0028)
House price growth	-0.0001	0.0427**
	(0.0190)	(0.0195)
Lagged house price growth	-0.0258	0.0458*
	(0.0187)	(0.0234)
Net commodity price increase	-0.0039	0.0036
	(0.0187)	(0.0042)
Lagged net commodity price increase	**0.0009**	**0.0156****
	(0.0024)	**(0.0059)**

Notes: HAC standard errors are reported in parentheses. ***, ** and * denote significance at 1%, 5% and 10% level, respectively.

3. The Model

In this section I describe the model[11] with a financial accelerator and FIs investing in two assets – tied to capital and to commodities. The model is very close to that of BGG. The main differences between them are that in this model firms use commodities as well as labor and capital as inputs to produce goods, and that FIs invest not only in the shares in capital issued by firms but also in commodities. As usual in the literature such as Kim and Loungani (1992), Wei (2003) and Dhawan and Jeske (2008), commodities need to be imported at an exogenous price.

3.1. Financial Market

The framework of the financial market is closely related to that of Gertler and Karadi (2011). Specifically, firms issue shares to acquire funds that are necessary for purchasing 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.

There are two kinds of contracts in the financial market: loan contracts between FIs and investors, and share contracts between firms and FIs.[12] FIs have their own net worth, N, which is not sufficient for investing in commodities and in shares in capital issued by firms. FIs thus enter into loan contracts with investors in order to borrow money.

As in BGG, FIs face idiosyncratic shocks, ω, to their returns. Therefore, the ex post gross return to investment of FI $i \in \{1, 2, \cdots, \infty\}$ is equal to $\omega_i R^F_{t+1}$, where R^F_{t+1} is the ex post aggregate return to investment of FIs. $\ln \omega$ follows a normal distribution with mean $-\frac{1}{2}\sigma^2$ and variance σ^2, and under this assumption, $E[\omega] = 1$. The CDF of ω is $F(\cdot)$ and the PDF is $f(\cdot)$. ω is i.i.d. across time and across FIs.[13]

3.1.1. Loan Contract between FIs and Investors

As in BGG, the costly state verification 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, which is a fixed fraction, μ, of the entire wealth of the FI.

In each period, FI i wishes to invest $Q_t S_{i,t}$ in shares in capital issued by firms, and $p_t x^F_{i,t}$ in commodities.[14] S is the quantity of the shares in capital issued by the firms, Q is the price of each share, which is equal to the price of each unit of capital, x^F is the units of the composite commodity used noncommercially, and p is the price of one unit of the composite commodity.

[11] See Online Appendix for the details of the model.
[12] Since there are no frictions in the share contracts between FIs and firms, the contracts are not described.
[13] See Online Appendix for details.
[14] In this paper, the subscript i denotes FIs.

Therefore, FI i needs to borrow $Q_t S_{i,t} + p_t x^F_{i,t} - N_{i,t+1}$ from investors. Accordingly, the FI's balance sheet is as given in Figure 3:

· **Assets**	· **Liabilities**
- Shares: QS	- Borrowing: $QS + px^F - N$
- Commodity: px^F	· **Equities**
	- Net worth: N

Figure 3: FI's balance sheet

FI i has to repay to investors the principal and interest, $Z_{i,t+1}\left(Q_t S_{i,t} + p_t x^F_{i,t} - N_{i,t+1}\right)$, 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 entire wealth of FI i.

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

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

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

$$\Psi(\bar{\omega}_i) = \Gamma(\bar{\omega}_i) - \mu G(\bar{\omega}_i). \tag{2}$$

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

$$E_t[\Psi(\bar{\omega}_{i,t+1}) R^F_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t})] = R_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t} - N_{i,t+1}), \tag{3}$$

where E_t is the expectations operation conditional on the information at t.

FIs choose the expenditure on investment, $Q_t S_{i,t} + p_t x^F_{i,t}$, and the threshold values of the idiosyncratic shocks, $\bar{\omega}_{i,t+1}$, so as to maximize their expected profits, $E_t\left[(1 - \Gamma(\bar{\omega}_{i,t+1}))\, R^F_{t+1} (Q_t S_{i,t} + p_t x^F_{i,t})\right]$. The first-order condition is

$$\frac{E_t[R^F_{t+1}]}{R_{t+1}} = E_t\left[\frac{\Gamma_\omega(\bar{\omega}_{i,t+1})}{(1 - \Gamma(\bar{\omega}_{i,t+1}))\, \Psi_\omega(\bar{\omega}_{i,t+1}) + \Gamma_\omega(\bar{\omega}_{i,t+1}) \Psi(\bar{\omega}_{i,t+1})}\right], \tag{4}$$

where $\Gamma_\omega(\cdot) = \frac{\partial \Gamma(\cdot)}{\partial \omega}$, $\Psi_\omega(\cdot) = \frac{\partial \Psi(\cdot)}{\partial \omega}$, and $\frac{E_t[R^F_{t+1}]}{R_{t+1}}$ is called the external finance premium.[15]

3.1.2. Aggregation of the Loan Contract

Since the left-hand side of equation (4) is determined exogenously to the financial market, every FI's choice for $E_t[\bar{\omega}_{i,t+1}]$ is the same. Thus, equation (4) can be aggregated:

$$\frac{E_t[R^F_{t+1}]}{R_{t+1}} = E_t\left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\,\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right]. \tag{5}$$

Aggregating the expected participation constraints, equation (3), yields

$$E_t[\Psi(\bar{\omega}_{t+1})R^F_{t+1}(Q_tS_t + p_tx^F_t)] = R_{t+1}(Q_tS_t + p_tx^F_t - N_{t+1}), \tag{6}$$

where $S_t = \sum_i S_{i,t}$, $x^F_t = \sum_i x^F_{i,t}$ and $N_{t+1} = \sum_i N_{i,t+1}$. Using equations (5) and (6), the relationship between FIs' leverage, $(Q_tS_t + p_tx^F_t)/N_{t+1}$, and the external finance premium can be obtained:

$$\frac{Q_tS_t + p_tx^F_t}{N_{t+1}} = \aleph\frac{E_t[R^F_{t+1}]}{R_{t+1}}, \tag{7}$$

where $\aleph = E_t\left[\frac{\{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})+\Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})\}^2}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})\Gamma_\omega(\bar{\omega}_{t+1})}\right]$. Since the numerator of $\aleph$ is positive, $1-\Gamma(\bar{\omega}_{t+1}) > 0$, $\Psi_\omega(\bar{\omega}_{t+1}) > 0$ and $\Gamma_\omega(\bar{\omega}_{t+1}) > 0$, $\aleph > 0$.[16] Therefore, leverage is increasing in the external finance premium.

3.1.3. FIs' Commodity Investment

Now, suppose that the composite commodity is storable, and that in period t FIs buy x^F_t units of the composite commodity at p_t and sell them at p_{t+1} in period $t+1$. As in Unalmis, Unalmis and Unsal (2012), FIs also need to cover the storage costs, $\kappa + \frac{\varphi}{2}x^F_t$, of storing one unit of the composite commodity, where $\kappa < 0$ reflects the convenience yield. Since it is assumed that $\varphi > 0$, the storage costs are increasing in x^F_t. FIs' expected profit of investing $p_tx^F_t$ in period t can be written by $\frac{bE_t[p_{t+1}]x^F_t}{R_{t+1}} - p_tx^F_t\left(1+\kappa+\frac{\varphi}{2}x^F_t\right)$, where $1-b>0$ is the wasted amount of the composite commodity in storing. Maximizing the expected profit yields the demand for commodity investment:

$$x^F_t = \frac{bE_t[p_{t+1}]}{\varphi p_tR_{t+1}} - \frac{(1+\kappa)}{\varphi}. \tag{8}$$

Accordingly, the realized return to FIs' investment in commodities, R^x_t, is

[15] See Online Appendix for details.
[16] See Online Appendix for details.

$$R_t^x = \frac{bp_t}{p_{t-1}R_t} - \left(\kappa + \frac{\varphi}{2}x_{t-1}^F\right). \tag{9}$$

For convenience, I define τ_t the ratio as of FIs' commodity investment $p_t x_t^F$ to their share investment $Q_t S_t$:[17]

$$\tau_t = p_t x_t^F / Q_t S_t. \tag{10}$$

Note that since each FI shares the identical rational expectation with other FIs, every FI's choice for τ_t is the same. Thus, the aggregate return to investment of FIs is

$$R_t^F = \frac{1}{1+\tau_t}(R_t^K + \tau_t R_t^x). \tag{11}$$

3.1.4. Dynamic Behavior of Net Worth

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

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

where $V_t = (1 - \Gamma(\bar{\omega}_t))\, R_t^F (Q_{t-1}S_{t-1} + p_{t-1}x_{t-1}^F)$ and $W_{F,t}$ is the labor incomes of FIs. Let γ^F be the survival probability for FIs. When an FI quits its business, it consumes all of its net worth, and the consumption of quitting FIs is thus

$$C_t^F = (1 - \gamma^F)V_t. \tag{13}$$

3.2. The Rest of the Economy

3.2.1. Household

A representative household chooses consumption, labor supply and real lending so as to maximize its utility. For simplicity, log utility function of consumption and separability between consumption and labor are assumed. The utility function is

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \frac{L_{C,t}^{1+\chi}}{1+\chi}\right), \tag{14}$$

[17] If $\tau_t = 0$, FIs invest all available funds in the shares in capital issued by firms, as in BGG.

where C_t is consumption, $L_{C,t}$ is the labor supply by households, β is the discount factor, and χ is the inverse of Frisch elasticity of labor supply.[18]

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 the real profits remitted by firms.

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

$$1 = \beta E_t \left[\frac{C_t}{C_{t+1}} R_{t+1} \right], \tag{16}$$

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

Equation (16) is the Euler equation, and equation (17) is the condition of intratemporal substitution between consumption and labor.

3.2.2. Final Goods Firms

There is a continuum of intermediate goods firms indexed by $j \in [0,1]$. They produce differentiated intermediate goods, $Y_t(j)$, at prices $P_t(j)$. Final goods firms bundle intermediate goods to produce final goods according to the following CES technology:

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{18}$$

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

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

$$Y_t(j) = \left(\frac{P_t(j)}{\mathbb{P}_t} \right)^{-\varepsilon} Y_t, \tag{19}$$

and the corresponding price index is

$$\mathbb{P}_t = \left(\int_0^1 P_t(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}. \tag{20}$$

3.2.3. Intermediate Goods Firms

A typical intermediate goods firm produces output using capital, labor and commodities. The production function is a nested CES with constant returns to scale, following Kim and

[18] Some papers such as Bodenstein, Erceg and Guerrieri (2011) assume that households consume commodities. However, for simplicity, I do not consider commodity consumption in the model, since it does not play a notable role in generating the results of this paper.

Loungani (1992) and Dhawan and Jeske (2008):

$$Y_t(j) = A_t\{(1-a)K_t(j)^{-\nu} + a x_t(j)^{-\nu}\}^{-\frac{\alpha}{\nu}} L_t(j)^{1-\alpha}, \tag{21}$$

where $x(j)$ is the units of the composite commodity used in production, $K(j)$ is the capital inputs, and $1-\alpha$ is the labor share of income. The parameter a determines the importance of the commodities. The parameter ν is equal to $\frac{1-\varsigma}{\varsigma}$, where ς is the elasticity of substitution between capital and commodities. A is the common productivity, and follows an AR(1) process as usual:

$$\ln A_t = \rho_A \ln A_{t-1} + u_t, \tag{22}$$

where u_t is the productivity shock. As in BGG, $L_t(j)$ is a composite of the labor that is supplied by households ($L_{C,t}(j)$) and FIs ($L_{F,t}(j)$). $L_t(j)$ is expressed by

$$L_t(j) = L_{C,t}(j)^{1-\Omega_F} L_{F,t}(j)^{\Omega_F}. \tag{23}$$

In each period, intermediate goods firms issue shares in order to purchase capital for production, which means that

$$Q_t K_{t+1} = Q_t S_t. \tag{24}$$

Firms purchase capital at the end of period $t-1$ to produce goods in period t, and sell the non-depreciated capital back to the capital goods producers at the end of period t. The first-order conditions of the cost minimization problem are

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

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

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

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

where δ is the depreciation rate, mc_t is the real marginal cost, and $\Delta_t = \int_0^1 \left(\frac{P_t(j)}{\mathbb{P}_t}\right)^{-\varepsilon} dj$ is the price dispersion term.

Commodity prices are determined exogenously, and follow AR(1)[19] as in Wei (2003):

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

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

where η_t is the commodity price shocks.

Firms 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 for one period is θ. Thus, the first-order condition for the optimal reset price, P_t^O, is

$$P_t^O = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{h=0}^{\infty} (\beta\theta)^h C_{t+h}^{-1} mc_{t+h} \mathbb{P}_{t+h}^{\varepsilon} Y_{t+h}}{E_t \sum_{h=0}^{\infty} (\beta\theta)^h C_{t+h}^{-1} \mathbb{P}_{t+h}^{\varepsilon-1} Y_{t+h}}. \tag{30}$$

Accordingly, the price index evolves according to

$$\mathbb{P}_t = \left[(1-\theta) P_t^{O^{1-\varepsilon}} + \theta \mathbb{P}_{t-1}^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{31}$$

3.2.4. Capital Goods Producers

The capital goods producers use their technology to convert final goods to capital goods. In each period they buy I_t of final 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

$$K_{t+1} = (1-\delta) K_t + I_t - \frac{\xi}{2} \frac{(K_{t+1} - K_t)^2}{K_t}, \tag{32}$$

where ξ is the parameter associated with the adjustment costs. The first-order condition gives the price of capital:

$$Q_t = 1 - \xi + \xi \frac{K_{t+1}}{K_t}. \tag{33}$$

3.2.5. Monetary Policy and Resource Constraint

The monetary authority follows a standard Taylor-type rule,

$$i_t = (1-\rho_I) i + \rho_I i_{t-1} + (1-\rho_I)\{\phi_\pi(\pi_t - \pi) + \phi_Y(\ln Y_t - \ln Y)\}, \tag{34}$$

where i_t is the nominal interest rate, and $\pi_t = \mathbb{P}_t / \mathbb{P}_{t-1}$. The variables without time subscript t denote their steady state values. The Fisher equation, $R_{t+1} = E_t\left[i_t/\pi_{t+1}\right]$, gives the relationship between the nominal and real interest rates.

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

$$Y_t = C_t + C_t^F + I_t + p_t x_t + p_t(x_t^F - b x_{t-1}^F) + \mu G(\bar{\omega}_t) R_t^F (Q_{t-1} K_t + p_{t-1} x_{t-1}^F). \tag{35}$$

The last term is the monitoring cost of investors.[20]

4. Model Analysis

4.1. Calibration

The parameter values are given in Table 2. The calibration is based on quarterly U.S. data.

First of all, the U.S. Commodity Futures Trading Commission and FRED data show that during the Q4 2007 to Q3 2015 period the value of FIs' net long position of commodity derivative contracts was in average 1.1% of the remaining total assets. τ is therefore set to 0.011, which means that FIs invest 1.1% of the amount that they invest in the shares in capital issued by firms, in commodities. I also consider one more cases for $\tau = 0$, in which FIs invest only in the shares in capital issued by firms. By considering two cases for τ, I can show how the responses of the macroeconomic variables to a negative commodity price shock change as FIs invest in commodities to different degrees.

In keeping with much of the literature, the discount factor, β, is 0.98, the inverse of Frisch elasticity of labor supply, χ, is set to 3, the depreciation rate, δ, is assumed to be 0.025, the parameter associated with capital adjustment costs, ξ, is 2.5, and the labor share of income, $1 - \alpha$, is equal to 0.64. The elasticity of substitution between intermediate inputs, ε, is set to 6, and the probability that a price does not adjust, θ, is assumed to be 0.75.

Following BGG, the share of FIs' labor inputs, Ω_F, is 0.01, and the rate of failure of FIs, $F(\bar{\omega})$, is 0.03/4. The steady state risk spread, $R^K - R$, is assumed to be 0.01, and I assume that the steady state leverage, $(K + x^F)/N$, is 4 (the same as in Gertler and Karadi, 2011), which implies that the steady state ratio of capital to the FIs' net worth, K/N, is equal to $4/(1+\tau)$ and that of commodity investment to net worth, x^F/N, is $4\tau/(1+\tau)$ by equation (10).

The parameter for the surviving amount of commodities stored, b, is assumed to be 0.97 which matches the estimation results of Deaton and Laroque (1996) that annual deterioration rate of commodities in storing is around 12%. The convenience yield, κ, is set to -0.11 consistent with about -0.4 of the annual convenience yield used in Ng and Ruge-Murcia (2000). The parameter associated with the storage costs, φ, is set to satisfy $R^K = R^x$.

As in Kim and Loungani (1992), I assume that the parameter related to the elasticity

[20] Note that, according to BGG, C_t^F and the monitoring cost have relatively low weights under any reasonable parameterization of the model, and thus have no recognizable effects on the dynamics.

of substitution between capital and commodity inputs in production, ν, is 0.7. The steady state capital/commodity ratio, K/x, is assumed to be 126.2.[21] Accordingly, the parameter related to the importance of commodities in production, a, is 0.005, which is determined by the values of K/x, R^K, δ and ν from equations (27) and (28) in the steady state.

Using the definition of the log-normal distribution, the steady state expected participation constraint and the first-order condition of the FI's problem, the steady state threshold value of the idiosyncratic shocks, $\bar{\omega}$, and the variance of $\ln\omega$, σ^2, can be obtained. Therefore, the monitoring cost, μ, and the probability of survival for FIs, γ^F, can be calculated. σ is 0.119, μ is 0.193, and γ^F is 0.94.

The parameters in the monetary policy rule are consistent with the standard literature. The autoregressive parameter, ρ_I, is 0.8, the policy weight on inflation, ϕ_π, is set to 1.5, and the policy weight on the output gap, ϕ_Y, is 0.1. Finally, the autoregressive parameter in commodity price, ρ, is equal to 0.976 which is estimated using Bayesian techniques.[22]

Table 2: Parameter values

Parameter	Value	Parameter	Value
β	0.98	φ	0.59
χ	3	ν	0.7
δ	0.025	a	0.005
ξ	2.5	σ	0.119
α	0.36	μ	0.193
ε	6	γ^F	0.94
θ	0.75	ρ_I	0.8
Ω_F	0.01	ϕ_π	1.5
b	0.97	ϕ_Y	0.1
κ	-0.11	ρ	0.976

4.2. Effects of a Negative Commodity Price Shock

This section shows how the model responds to a negative commodity price shock. By conducting this analysis, the way in which the existence of commodities as an asset class can dampen the effects of commodity price shocks on the economy can be shown. Figure 4 presents the responses of the model, with two values of τ, to a negative 1% deviation shock to commodity prices.

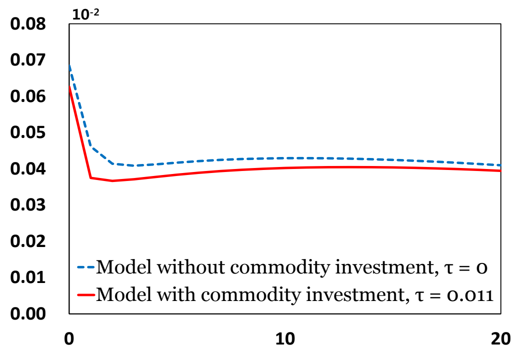
[21] This is different from Kim and Loungani (1992), who assume that the steady state capital/energy ratio is 200. However, in this model firms use all commodities, rather than only energy. Considering that the weight of energy in the IMF's commodity price index is 0.631, $200 \times 0.631 = 126.2$ as the steady state capital/commodity ratio seems appropriate.

[22] Demeaned commodity price index divided by GDP deflator for the period Q1 1960 to Q2 2018 is used as demeaned real commodity prices. A Beta distribution, 0.96 and 0.05 are used as prior distribution, mean and standard deviation, respectively, and posterior mean and 90% confidence interval are 0.9763 and [0.9584, 0.9997], respectively.

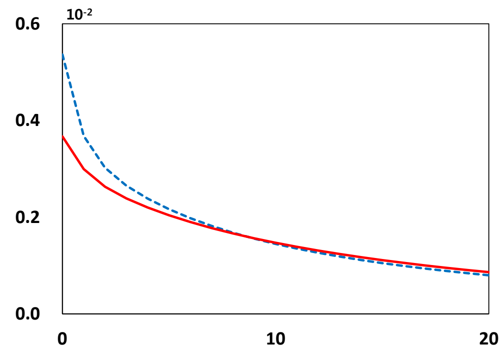
First, consider the case of $\tau_t = \tau = 0$ for all t, in which FIs invest only in the shares in capital issued by firms. Since a negative commodity price shock leads to a fall in firms' input costs, their demands for both commodities and capital increase. Thus, the price of capital, Q, jumps, which leads to a rise in FIs' returns on investment in the shares in capital issued by firms, R^K. Since from equation (11) the FIs' aggregate return on investment, R^F, is equal to R^K when $\tau_t = 0$, R^F increases. Due to the realized participation constraint, equation (6), a rise in R^F brings about a fall in the threshold value of the idiosyncratic shocks, $\bar{\omega}$, since $\Psi_\omega > 0$. Because R^F and the share of the profits going to FIs in the loan contract, $1 - \Gamma(\bar{\omega})$, increase ($\mathit{\Gamma}_\omega > 0$), the net worth of FIs, N, rises in accordance with equation (12). Therefore, owing to the increases in N and in the demand for capital, the investment goes up and output thus expands.

However, since when $\tau = 0.011$ ($\tau_t > 0$) the shock brings about a fall in the FIs' returns on investment in commodities, R^x, R^F rises by less even despite a rise in R^K. The smaller rise in R^F leads to a lesser amount of decrease in $\bar{\omega}$, and $1 - \Gamma(\bar{\omega})$ thus rises by less. Given the smaller increases in R^F and $1 - \Gamma(\bar{\omega})$, N also rises by less. FIs' investment in the shares in capital issued by firms thus increases by less. Although demand for capital grows due to a fall in commodity prices, investment rises by less than when $\tau = 0$ owing to the smaller increase in N. Output therefore increases by less than the case of $\tau = 0$. In short, if FIs hold the assets tied to commodities, N increases by less, and thus investment and output rise by less.

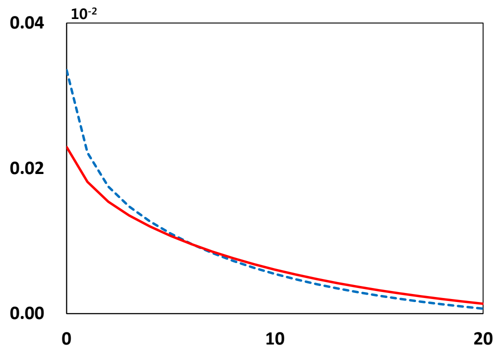
To summarize, if FIs own assets tied to commodities, investment and output will increase to a lesser extent following a negative commodity price shock. This is mainly because a fall in commodity prices causes not only an increase in the returns to FIs' investments in assets tied to capital, but also a fall in their returns on investment in commodities. As a result, FIs' returns on total investment go up by less than in the models in which FIs hold only assets associated with capital, and their net worth hence rises by less. Thus, considering that commodities have begun to function as an asset class since the mid-2000s, and that according to the empirical evidence in Section 2 and the literature such as Blanchard and Galí (2010) the impacts of commodity price shocks have weakened since the mid-2000s, these results are consistent with the hypothesis that commodities as an asset class have played an important role in the recently reduced impacts of commodity price shocks on the economy.



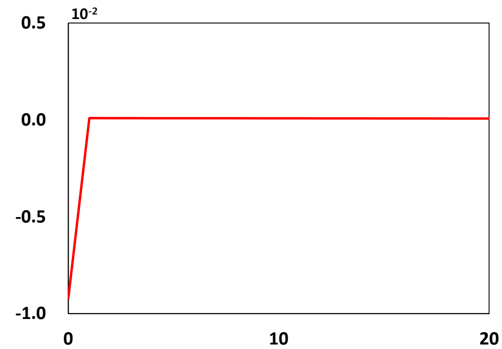
(a) Output



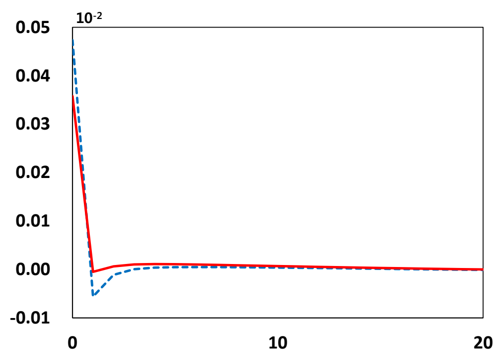
(b) Investment



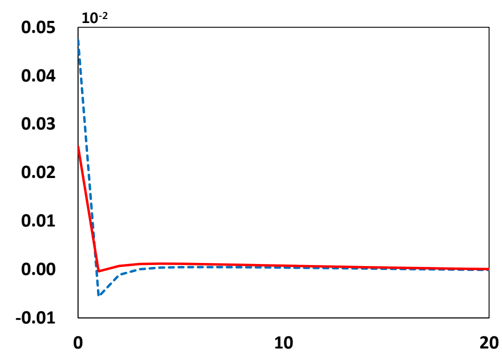
(c) Price of capital



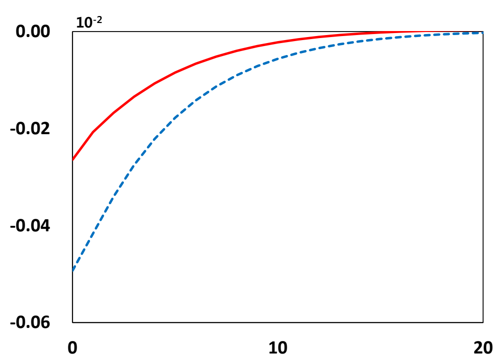
(d) Return on commodities



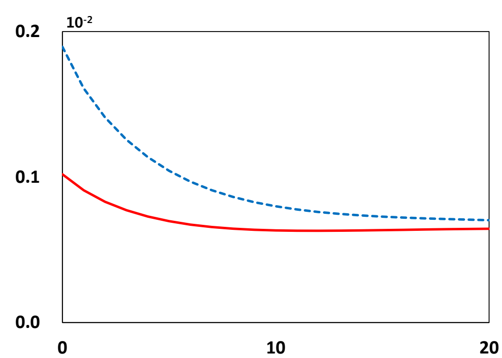
(e) Return on capital



(f) Return on total investment



(g) Threshold values of idiosyncratic shocks



(h) Net worth

Figure 4: Responses of the model to a negative commodity price shock

4.3. 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 risks to their investments in the shares in capital issued by firms stemming from commodity price shocks.

To be specific, the demand for commodities in production, x, is decreasing in commodity prices, and the return to capital, R^K, is increasing in x. Hence, R^K is decreasing in commodity prices. However, the return on commodity investment, R^x, is increasing in commodity prices. Therefore, R^K and R^x react in the opposite directions to changes in commodity prices, which enables FIs to hedge against the risks from commodity price shocks to their investments in the shares in capital issued by firms by investing in commodities. For instance, a rise in commodity prices will lead to an increase in R^x by equation (9), but to a fall in R^K by equations (27) and (28). If FIs do not invest in commodities, their returns on investment, R^F, will fall. In this model, however, since FIs hold commodities as an asset R^F declines due to a rise in R^x by less than when they do not hold them, i.e. when FIs invest in commodities their returns on investment fluctuate by less in response to commodity price shocks.

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 risks, which is noted in the literature such as Basu and Gavin (2011). In models in which FIs invest only in capital, their returns on investment depend solely on the returns to capital, and there are no instruments with which FIs can diversify the risk of investment associated with capital. In this model FIs do have such instruments, however, and this model is thus more relevant than others in considering the existence of commodities as an instrument for hedging by FIs.

5. Conclusion

This paper has developed a model with a financial accelerator and FIs investing in two assets – tied to capital and to commodities – by extending the model of BGG to explain the role of commodities as an asset class in the recently declined effects of commodity price shocks on the economy. The simulation results of the model show that FIs' investment in commodities has been an important factor explaining these recent reduced impacts of commodity price shocks.

A negative commodity price shock causes both a rise in the return on FIs' investments in assets tied to capital and a fall in the return on their investments in commodities. In models such as BGG, in which there is no asset tied to commodities, there is only the former effect and the net worth of FIs thus increases. In this model, however, in which FIs invest in commodities as assets also, both effects exist, and the net worth of FIs therefore rises by less. As a consequence, FIs' investment in the shares in capital issued by firms increases by less, which results in smaller responses of the economy to commodity price shocks; i.e. the presence of commodities as an asset class makes the economy less volatile in response to commodity price shocks.

The existence of commodities as an asset class in this model is moreover consistent with the fact that FIs use commodity derivatives to hedge against equity risk. Specifically, since the returns to capital and to commodities react in the opposite directions when commodity prices change, FIs can hedge against the risk of investment in the shares in capital issued by firms to commodity price shocks by investing in commodities.

It should be finally noted that this paper does not study policy effects on the economy. However, the framework in this model allows such analyses with simple extensions, and it would be interesting to see future research that studies how policy effects change and to analyze the optimal policies to commodity price shocks when commodities as an asset class are present in the model.

References

Albertazzi, U. and L. Gambacorta (2009). Bank profitability and the business cycle. *Journal of Financial Stability 5*, 393–409.

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 (2010). The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? International Dimensions of Monetary Policy, edited by Jordi Galí and Mark J. Gertler, University of Chicago Press.

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

Borio, C., L. Gambacorta, and B. Hofmann (2017). The influence of monetary policy on bank profitability. *International Finance 20*, 48–63.

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

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

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

Deaton, A. and G. Laroque (1996). Competitive storage and commodity price dynamics. *Journal of Political Economy 104*, 896–923.

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.

Hamilton, J. D. (1996). This is what happened to the oil price-macroeconomy relationship. *Journal of Monetary Economics 38*, 215–220.

Hardy, D. C. and C. Pazarbaşioğlu (1999). Determinants and leading indicators of banking crises: Further evidence. *IMF Staff Papers 46*, 247–258.

Katayama, M. (2013). Declining effects of oil price shocks. *Journal of Money, Credit and Banking 45*, 977–1016.

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.

Ng, S. and F. J. Ruge-Murcia (2000). Explaining the persistence of commodity prices. *Computational Economics 16*, 149–171.

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.

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.

Unalmis, D., I. Unalmis, and F. D. Unsal (2012). On the sources and consequences of oil price shocks: The role of storage. *IMF Economic Review 60*, 505–532.

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

Online Appendix (not for publication)

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

From the definition of a 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 the standard normal distribution. $G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega) d\omega = E[\omega \mid \omega \leq \bar{\omega}] \Pr(\omega \leq \bar{\omega}) = \exp[-\frac{1}{2}\sigma^2 + \frac{1}{2}\sigma^2]\Phi(\frac{\ln \bar{\omega} + \frac{1}{2}\sigma^2 - \sigma^2}{\sigma}) = \Phi(\frac{\ln \bar{\omega} - \frac{1}{2}\sigma^2}{\sigma})$.

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:

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

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

$$\mathit{\Gamma}_\omega(\bar{\omega}) = \frac{\partial(G(\bar{\omega}) + (1 - F(\bar{\omega}))\bar{\omega})}{\partial \omega} = 1 - F(\bar{\omega}) > 0, \tag{A.3}$$

$$\Psi_\omega(\bar{\omega}) = \frac{\partial(\mathit{\Gamma}(\bar{\omega}) - \mu G(\bar{\omega}))}{\partial \omega} = \mathit{\Gamma}_\omega(\bar{\omega}) - \mu G_\omega(\bar{\omega}), \tag{A.4}$$

where $\phi(\cdot)$ is the PDF of the 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 $h(\bar{\omega}) = \frac{f(\bar{\omega})}{1 - F(\bar{\omega})}$ is the hazard rate. Since $\frac{\partial\{\bar{\omega} h(\bar{\omega})\}}{\partial \bar{\omega}} > 0$ as in BGG, 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 $\Psi_\omega(\bar{\omega}) > 0$.

FI i's profit maximization problem FI i's profit maximization problem can be expressed by

$$\max_{\bar{\omega}_{i,t+1}, \left(Q_t S_{i,t} + p_t x^F_{i,t}\right)} E_t\left[(1 - \Gamma(\bar{\omega}_{i,t+1}))R^F_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t})\right],$$

subject to the expected participation constraint. The corresponding Lagrangian is

$$\mathcal{L} = E_t[(1 - \Gamma(\bar{\omega}_{i,t+1}))R^F_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t}) +$$

$$\lambda_{i,t+1}\{\Psi(\bar{\omega}_{i,t+1})R^F_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t}) - R_{t+1}(Q_t S_{i,t} + p_t x^F_{i,t} - N_{i,t+1})\}],$$

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

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

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

Simplifying these two equations yields

$$\lambda_{i,t+1} = E_t\left[\frac{\Gamma_\omega(\bar{\omega}_{i,t+1})}{\Psi_\omega(\bar{\omega}_{i,t+1})}\right], \tag{A.5}$$

$$\frac{E_t[R_{t+1}^F]}{R_{t+1}} = E_t\left[\frac{\lambda_{i,t+1}}{(1-\Gamma(\bar{\omega}_{i,t+1})) + \lambda_{i,t+1}\Psi(\bar{\omega}_{i,t+1})}\right]. \tag{A.6}$$

Relationship between the external finance premium and leverage From equations (5) and (6) in the paper,

$$E_t\left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right] = E_t\left[\frac{Q_t S_t + p_t x_t^F - N_{t+1}}{\Psi(\bar{\omega}_{t+1})(Q_t S_t + p_t x_t^F)}\right]. \tag{A.7}$$

From equation (A.7),

$$\frac{Q_t S_t + p_t x_t^F}{N_{t+1}} = E_t\left[\frac{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})}\right]. \tag{A.8}$$

By equation (5) in the paper and equation (A.8),

$$\frac{Q_t S_t + p_t x_t^F}{N_{t+1}} = E_t\left[\frac{\{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})\}^2}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1})\Gamma_\omega(\bar{\omega}_{t+1})}\right]\frac{E_t[R_{t+1}^F]}{R_{t+1}}. \tag{A.9}$$

Summary of the model

$$\frac{E_t[R_{t+1}^F]}{R_{t+1}} = E_t\left[\frac{\Gamma_\omega(\bar{\omega}_{t+1})}{(1-\Gamma(\bar{\omega}_{t+1}))\Psi_\omega(\bar{\omega}_{t+1}) + \Gamma_\omega(\bar{\omega}_{t+1})\Psi(\bar{\omega}_{t+1})}\right], \tag{A.10}$$

$$\Psi(\bar{\omega}_t)R_t^F(Q_{t-1}K_t + p_{t-1}x_{t-1}^F) = R_t(Q_{t-1}K_t + p_{t-1}x_{t-1}^F - N_t), \tag{A.11}$$

$$x_t^F = \frac{bE_t[p_{t+1}]}{\varphi p_t R_{t+1}} - \frac{(1+\kappa)}{\varphi}, \tag{A.12}$$

$$R_t^x = \frac{bp_t}{p_{t-1}R_t} - \left(\kappa + \frac{\varphi}{2}x_{t-1}^F\right), \tag{A.13}$$

$$p_t x_t^F = \tau_t Q_t K_{t+1}, \tag{A.14}$$

$$R_t^F = \frac{1}{1+\tau_t}(R_t^K + \tau_t R_t^x), \tag{A.15}$$

$$N_{t+1} = \gamma^F(1-\Gamma(\bar{\omega}_t))R_t^F(Q_{t-1}K_t + p_{t-1}x_{t-1}^F) + W_{F,t}, \tag{A.16}$$

$$C_t^F = (1-\gamma^F)(1-\Gamma(\bar{\omega}_t))R_t^F(Q_{t-1}K_t + p_{t-1}x_{t-1}^F), \tag{A.17}$$

$$1 = \beta E_t \left[\frac{C_t}{C_{t+1}} R_{t+1} \right], \tag{A.18}$$

$$W_t = C_t L_{C,t}^{\chi}, \tag{A.19}$$

$$Y_t \Delta_t = A_t \{(1-a)K_t^{-\nu} + a x_t^{-\nu}\}^{-\frac{\alpha}{\nu}} L_{C,t}^{(1-\alpha)(1-\Omega_F)}, \tag{A.20}$$

$$\ln A_t = \rho_A \ln A_{t-1} + \varepsilon_t, \tag{A.21}$$

$$W_t = (1-\alpha)(1-\Omega_F) mc_t \frac{\Delta_t Y_t}{L_{C,t}}, \tag{A.22}$$

$$W_{F,t} = (1-\alpha)\Omega_F mc_t \Delta_t Y_t, \tag{A.23}$$

$$R_t^K = \frac{1}{Q_{t-1}} \left\{ (1-\delta) Q_t + \alpha(1-a) mc_t K_t^{-\nu-1} \frac{\Delta_t Y_t}{(1-a)K_t^{-\nu} + a x_t^{-\nu}} \right\}, \tag{A.24}$$

$$p_t = a\alpha mc_t x_t^{-\nu-1} \frac{\Delta_t Y_t}{(1-a)K_t^{-\nu} + a x_t^{-\nu}}, \tag{A.25}$$

$$\ln p_t = \rho \ln p_{t-1} + \eta_t, \tag{A.26}$$

$$x_{1,t} = Y_t mc_t / C_t + \beta\theta E_t \left[\pi_{t+1}^{\varepsilon} x_{1,t+1} \right], \tag{A.27}$$

$$x_{2,t} = Y_t / C_t + \beta\theta E_t \left[\pi_{t+1}^{\varepsilon-1} x_{2,t+1} \right], \tag{A.28}$$

$$\Delta_t = (1-\theta) \left(\frac{\varepsilon}{\varepsilon-1} \frac{x_{1,t}}{x_{2,t}} \right)^{-\varepsilon} + \theta \pi_t^{\varepsilon} \Delta_{t-1}, \tag{A.29}$$

$$\pi_t^{1-\varepsilon} = (1-\theta) \left(\frac{\varepsilon}{\varepsilon-1} \frac{\pi_t x_{1,t}}{x_{2,t}} \right)^{1-\varepsilon} + \theta, \tag{A.30}$$

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

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

$$i_t = (1-\rho_I) i + \rho_I i_{t-1} + (1-\rho_I)\{\phi_\pi(\pi_t - \pi) + \phi_Y(\ln Y_t - \ln Y)\}, \tag{A.33}$$

$$R_{t+1} = E_t \left[i_t / \pi_{t+1} \right], \tag{A.34}$$

$$Y_t = C_t + C_t^F + I_t + p_t x_t + p_t(x_t^F - b x_{t-1}^F) + \mu G(\bar{\omega}_t) R_t^F (Q_{t-1} K_t + p_{t-1} x_{t-1}^F). \tag{A.35}$$