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Commodity Prices, Financial Frictions, and Macroprudential Policies *

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Abstract

Fluctuations in commodity prices have significant effects on output and financial stability in emerging countries. We examine the effect of macroprudential policies on commodity-exporting countries, which consist of two sectors—the commodity-producing sector and final goods sector. When a commodity-exporting country suffers from volatile fluctuations in commodity prices, we find that macroprudential policy in each sector is welfare-enhancing and that it is optimal to impose macroprudential policies in both sectors. We also show that macroprudential policies are more effective in improving welfare for commodity-exporting economies suffering from a stronger link between commodity prices and interest rate spreads, higher sensitivity of interest spreads to debt, and larger commodity price shocks.

Keywords: macroprudential policies, commodity-exporting countries, DSGE model, financial frictions, emerging economies, Mongolia
JEL Classification: E32, E44, F32, O20, Q48

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1 Introduction

Sharp fluctuations in commodity prices pose a significant risk to commodity-exporting economies. The recent literature on the business cycles of emerging economies reports that commodity price shocks have a sizable contribution to business cycle fluctuations (e.g., Shousha, 2016; Fernández et al., 2018; Drechsel and Tenreyro, 2018). Kitano (2021) shows that world commodity price shocks have a significant impact on Asian commodity-exporting economies using a structural vector auto-regression (SVAR) analysis. By analyzing 60 low-income countries, Eberhardt and Presbitero (2021) show that the volatility of commodity prices is a significant predictor of banking crises. Using a sample of 71 commodity exporters among emerging and developing economies, Kinda et al. (2018) demonstrate that negative commodity price shocks tend to weaken the financial sector and can lead to banking crises. They show that harmful effects tend to occur in countries with poor quality of governance, high public debt, and low financial development but are less common in countries with a diversified export base, holding sovereign wealth funds, and implementing macroprudential policies.[1]

Mongolia is one of the commodity-exporting countries that has suffered from the sharp fluctuations in commodity prices. Figure 1 illustrates the commodity price fluctuations faced by Mongolia.[2] Strong growth in emerging market economies, particularly in East Asia, contributed to a surge in commodity prices

[1]Using a DSGE model, Kitano and Takaku (2023) show that it is effective for commodity-exporting countries to hold sovereign wealth funds with the objective of mitigating the exogenous shock of volatile fluctuations in commodity prices.

[2]The export-weighted commodity price index for Mongolia in Figure 1 is obtained by applying the country-specific commodity-export weights to the corresponding world-commodity prices. For more details, please refer to Kitano (2021, page 2). For the other Asian commodity exporting countries, see Kitano and Takaku (2023, Figure 1).

in the first decade of the 2000s (Aslam et al., 2016). However, the global financial crisis caused a sharp decrease in commodity prices. After recovering for some time, commodity prices fell again in the latter half of the 2010s. The slow growth in emerging economies and the increasing supply of commodities mainly explain this. When the pandemic began in early 2020, commodity prices sharply declined again. However, the limited supply and recovering demand subsequently raised commodity prices sharply. Recent volatile fluctuations in commodity prices are likely to pose significant risks and cause great concern for policymakers in commodity-exporting economies.

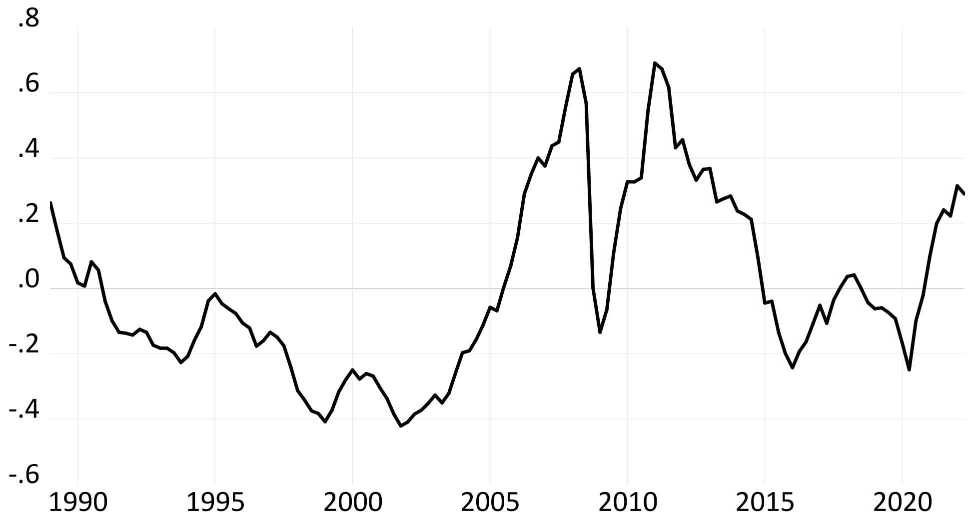


Figure 1: The export-weighted commodity price index of Mongolia

Note: For the export price data, we use the World Bank commodity price data ("pink sheet"). For the export weight data, we use the World Integrated Trade Solution (WITS) database. By applying Mongolia's country-specific commodity-export weights to the corresponding world-commodity prices, we obtain the export-weighted commodity price index for Mongolia.

Volatile fluctuations in commodity prices can also lead to banking crises in emerging countries. Eberhardt and Presbitero (2021) show that two-thirds of banking crises between 1963 and 2015 happened when commodity price volatility was higher than its short-run average. Figure 2 depicts the volatility of Mongolia's export-weighted commodity price index. Following Bleaney and Greenaway (2001), Cavalcanti et al. (2015), and Eberhardt and Presbitero (2021), we estimate the conditional volatility from a GARCH(1,1) model using a simple regression of the first difference of the commodity price index on a constant. Figure 2 reveals that volatility was remarkably high during 2008-9, when Mongolia experienced a series of banking crises. The banking crises in Mongolia began in 2008. Volatility in commodity prices due to the global financial crisis severely affected Mongolia's economy. Specifically, the price of copper—Mongolia's main export commodity—fell by 65 percent between April 2008 and March 2009 (IMF, 2009). The prices of other export commodities, such as coal, zinc, and crude oil, also fell significantly. The collapse of mineral prices substantially worsened Mongolia's fiscal balance, as mining-related revenues accounted for more than one-third of budget revenues at the peak of the commodity boom in 2007. The trade balance also deteriorated markedly through late 2008 and early 2009, owing to the collapse of mineral export prices. The banking sector was also affected by the global financial crisis and the subsequent collapse of mineral prices. The asset quality of the banking sector deteriorated, and the proportion of non-performing loans rose to 13.7% in July 2009 from 2.7% in May 2008, which peaked at 25% in November 2009 (Honma, 2015). This vicious circle of shrinking balance sheets reduced banks' liquidity and further constrained their lending. Anod Bank, the fourth-largest bank in Mongolia, was placed under administrative control in December 2008. After Anod Bank, bank failures continued to occur. The government established a new bank, the State Bank, in 2009, after the failure of Savings Bank, the fifth-largest bank in Mongolia.

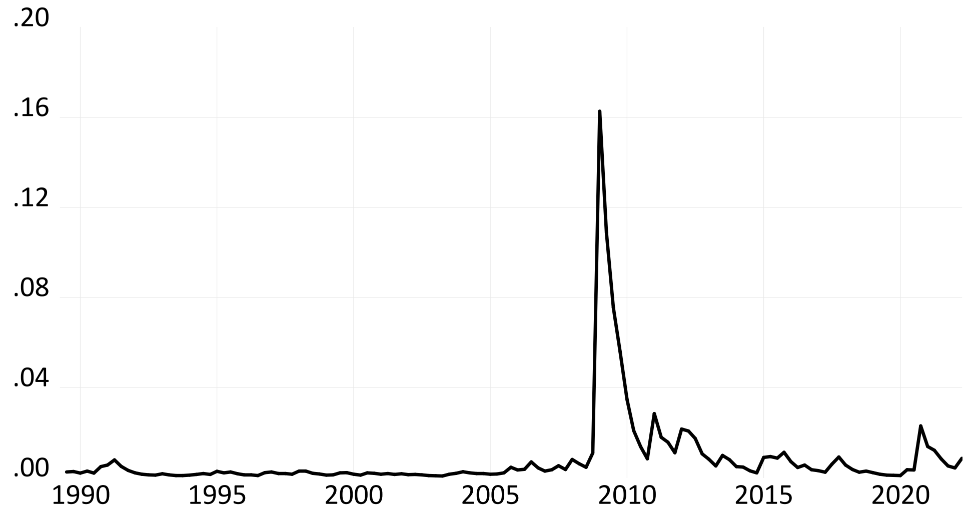


Figure 2: The volatility of Mongolia's export-weighted commodity price index
Note: The export-weighted commodity price index of Mongolia is shown in Figure 1. Its volatility is derived via GARCH(1,1), as described in the text.

Against this background, we examine the role of macroprudential policies in commodity-exporting economies facing recent volatile commodity prices using a dynamic stochastic general equilibrium (DSGE) model. The quantitative analysis in this paper focuses on Mongolia, which experienced a banking crisis during 2008-9.[3] As mentioned above, Kinda et al. (2018) empirically show that negative commodity price shocks tend to weaken the financial sector but that adverse effects are less common in countries implementing macroprudential policies. Studies using DSGE models to examine the effect of macroprudential policies in commodity-exporting countries are limited.[4] Exceptions are González et al. (2015) and Villca

[3]For the banking crises in other countries, see Eberhardt and Presbitero (2021).
[4]There exist many previous studies on macroprudential policies (although they do not focus on commodity-exporting countries) (e.g., Kannan et al., 2012; Angeloni and Faia, 2013; Unsal,

(2022). However, in their DSGE models, commodity production is assumed to evolve exogenously, and there is no optimization problem in the commodity sector. By contrast, unlike González et al. (2015) and Villca (2022), commodity production is endogenously determined in our model. Commodities are produced using capital and labor, exported to foreign countries, and used as inputs in the production of other sectors. As Drechsel and Tenreyro (2018) show, it is necessary to incorporate the commodity sector with endogenous production into DSGE models to capture the distinctive role of commodities in commodity-exporting economies.

The remainder of this paper is organized as follows. In Section 2, we present a small open economy model of commodity-exporting countries consisting of final goods and commodity-producing sectors à la Drechsel and Tenreyro (2018) but also augmented with a banking sector. We also calibrate our model to match the key characteristics of the Mongolian economy. Section 3 examines the welfare-improving effects of macroprudential policies. Finally, conclusions are presented in Section 4.

2 Model

A small open economy consists of households, non-financial firms, banks, and the government. Firms are divided into two sectors: a final goods sector and a commodity sector. The model framework is based on that of Drechsel and Tenreyro (2018), who embed a commodity sector and a negative association between commodity prices and interest spreads in a standard real business cycle model of a small open economy (e.g., Aguiar and Gopinath, 2007; Garcia-Cicco et al., 2010).

2013; Angelini et al., 2014; Levine and Lima, 2015; Ghilardi and Peiris, 2016; De Paoli and Paustian, 2017; Kitano and Takaku, 2020; Benbouzid et al., 2022).

However, we incorporate a banking sector à la Gertler and Kiyotaki (2010) into the small open economy model augmented with final goods and commodity sectors. Banks use deposits obtained from households and their net worth to make loans to non-financial firms. The government uses macroprudential policies to regulate bank lending to non-financial firms.

2.1 Households

Following Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), we assume that a representative household comprises bankers (f) and workers ($1-f$). Both types of members return wages and dividends to the representative households. Perfect consumption insurance is assumed for households. A banker remains the same in the next period with probability σ. $(1-\sigma)f$ bankers become workers in the next period, and the same number of workers become bankers. This implies that the fraction of each type of member remains constant over time. Households provide new bankers with start-up funds, and exiting bankers transfer their retained earnings to households.

A household's expected lifetime utility is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[C_t - \frac{\theta}{\eta^f}(H_t^f)^{\eta^f} - \frac{\theta}{\eta^c}(H_t^c)^{\eta^c}\right]^{1-\gamma} - 1}{1-\gamma}, \tag{1}$$

where E_0 denotes the mathematical expectation operator conditional on the information available at time 0. C_t is final goods consumption. H_t^f and H_t^c are the labor supplies to the final goods and commodity sectors, respectively. The parameters $\beta \in (0,1)$, $\gamma\,(>0)$, $\theta\,(>0)$, η^f, and η^c denote the discount factor, the inverse of the intertemporal elasticity of substitution, curvature parameters on labor, and the labor coefficients, respectively.

A household's budget constraint is given by

$$C_t + D_t + (1 + r_t^w)B_{t-1} + T_t = w_t^f H_t^f + w_t^c H_t^c + (1 + r_t^b)D_{t-1} + B_t + \Pi_t, \qquad (2)$$

where D_t is bank deposits, B_t is foreign debt, and T_t is a lump-sum tax. Π_t denotes the dividends from banks and non-financial firms. w_t^f and w_t^c denote the real wages in each respective sector. r_t^b denotes the interest rate on bank deposits. The interest rate on foreign borrowing r_t^w comprises the (exogenous) world interest rate r^*, country premium on foreign debt, and effect of commodity prices on interest rate spreads.

$$r_t^w = r^* + \psi(e^{\tilde{B}_t - \tilde{B}} - 1) - \chi(\ln p_t^c - \ln p^c), \qquad (3)$$

where p_t^c and p^c denote the commodity price and its steady-state level, respectively. $\tilde{B}_t$ and $\tilde{B}$ denote the aggregate (per capita) foreign debt and its steady-state level, respectively. Similar to related studies, we assume that the country premium is an increasing function of foreign debt to ensure the stationarity of foreign debt.[5] The parameter ψ denotes the debt elasticity of spread. The last term represents the effect of commodity prices on interest rate spreads. The parameter $\chi\,(> 0)$ represents the sensitivity of interest rate spreads to commodity prices. Following recent empirical evidence (e.g., Bastourre et al., 2012; Shousha, 2016; Fernández et al., 2018; Drechsel and Tenreyro, 2018), we assume that when world commodity prices decrease (increase), interest rate spreads rise (fall).[6]

[5]The small open economy model with incomplete asset markets features equilibrium dynamics that possess a random walk component. See Schmitt-Grohé and Uribe (2003) for further details.

[6]Boehm et al. (2021) find that lower (higher) export commodity prices are associated with

The household's first-order optimality conditions with respect to C_t, H_t^f, H_t^c, D_t, and B_t are

$$\left[C_t - \frac{\theta}{\eta^f}(H_t^f)^{\eta^f} - \frac{\theta}{\eta^c}(H_t^c)^{\eta^c}\right]^{-\gamma} = \lambda_t, \tag{4}$$

$$\left[C_t - \frac{\theta}{\eta^f}(H_t^f)^{\eta^f} - \frac{\theta}{\eta^c}(H_t^c)^{\eta^c}\right]^{-\gamma} \theta(H_t^f)^{\eta^f-1} = \lambda_t w_t^f, \tag{5}$$

$$\left[C_t - \frac{\theta}{\eta^f}(H_t^f)^{\eta^f} - \frac{\theta}{\eta^c}(H_t^c)^{\eta^c}\right]^{-\gamma} \theta(H_t^c)^{\eta^c-1} = \lambda_t w_t^c, \tag{6}$$

$$\lambda_t = \beta(1 + r_t^b)E_t\{\lambda_{t+1}\}, \tag{7}$$

and

$$\lambda_t = \beta(1 + r_t^w)E_t\{\lambda_{t+1}\}, \tag{8}$$

respectively, where λ_t is the Lagrange multiplier on Eq. (2). In addition, because we assume that households are identical, we know that the aggregate (per capita) debt level is equal to the individual's debt level:

$$\tilde{B}_t = B_t. \tag{9}$$

2.2 Banks

The balance sheet of a bank is given by

$$Q_t^f s_t^f + Q_t^c s_t^c = n_t + d_t. \tag{10}$$

Q_t^f and s_t^f respectively denote the price and quantity of a bank's financial claims on final goods producers. Q_t^c and s_t^c respectively denote the price and quantity

higher (lower) EMBI spreads.

of a bank's financial claims on commodity goods producers. n_t and d_t denote net worth and deposits from households, respectively.

The bank's net worth evolves according to the difference between earnings on assets and payments on liabilities.

$$n_t = (1 - \mathcal{T}_t^f) R_{k,t}^f Q_{t-1}^f s_{t-1}^f + (1 - \mathcal{T}_t^c) R_{k,t}^c Q_{t-1}^c s_{t-1}^c - (1 + r_t^b) d_{t-1} + \zeta_t, \qquad (11)$$

where $R_{k,t}^f$ and $R_{k,t}^c$ are the gross return on assets in the two sectors, and ζ_t is the government's lump-sum transfer to a bank. $\mathcal{T}_t^f$ and $\mathcal{T}_t^c$ denote the tax rates on a bank's asset holdings in the two sectors. Under macroprudential policies, the government individually imposes taxes on banks' lending to the two sectors.

Considering the probability of exiting the banking industry, the bank maximizes its expected terminal wealth:

$$V_t = E_t \sum_{i=1}^{\infty} (1 - \sigma) \sigma^{i-1} \Lambda_{t,t+i} n_{t+i}, \qquad (12)$$

where

$$\Lambda_{t,t+i} \equiv \beta^i \frac{\lambda_{t+i}}{\lambda_t}. \qquad (13)$$

Here, $1 - \sigma$ is the probability of exiting the banking industry in the next period.

We introduce an agency problem à la Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), which implies that a bank's ability to expand its balance sheet is limited to a certain level. We assume that a banker can transfer some fraction of "divertable" assets to the household, and a bank becomes bankrupt if it diverts its assets. This introduces an incentive constraint:

$$V_t \geq \Theta(Q_t^f s_t^f + Q_t^c s_t^c), \tag{14}$$

where Θ denotes the "divertable" fraction of assets. The left-hand side of Eq.(14) represents the banker's loss from bankruptcy. The right-hand side of Eq.(14) is the banker's gain from the bankruptcy. Therefore, the left-hand side must not be less than the right-hand side, ensuring households are willing to lend to a bank. In other words, the incentive constraint (14) limits a bank's ability to expand its balance sheet.

As Appendix A1 shows, we can express V_t as follows.

$$V_t(s_t^f, s_t^c, n_t) = \mu_t^f Q_t^f s_t^f + \mu_t^c Q_t^c s_t^c + \mathcal{V}_t n_t, \tag{15}$$

with

$$\mu_t = E_t \Lambda_{t,t+1} \Omega_{t+1}[(1 - \mathcal{T}_t^f) R_{k,t+1}^f - (1 + r_{t+1}^b)], \tag{16}$$

$$\mu_t = E_t \Lambda_{t,t+1} \Omega_{t+1}[(1 - \mathcal{T}_t^c) R_{k,t+1}^c - (1 + r_{t+1}^b)], \tag{17}$$

where

$$\mu_t \equiv \mu_t^f = \mu_t^c,$$

and

$$\mathcal{V}_t = E_t \Lambda_{t,t+1} \Omega_{t+1}(1 + r_{t+1}^b), \tag{18}$$

where

$$\Omega_t \equiv (1 - \sigma) + \sigma(\phi_t \mu_t + \mathcal{V}_t), \tag{19}$$

and

$$\phi_t \equiv \frac{\mathcal{V}_t}{\Theta - \mu_t}. \tag{20}$$

The analytical insights from the banks' optimization problem are as follows. First, we consider the left-hand sides of Eqs. (16) and (17). As Appendix A1 shows, we have $\mu_t \equiv \mu_t^f = \mu_t^c$, $\mu_t^f \equiv \frac{\mathcal{V}_t^f}{Q_t^f} - \mathcal{V}_t$, and $\mu_t^c \equiv \frac{\mathcal{V}_t^c}{Q_t^c} - \mathcal{V}_t$. Here, $\frac{\mathcal{V}_t^f}{Q_t^f}$ and $\frac{\mathcal{V}_t^c}{Q_t^c}$ imply the marginal value of assets, and $\mathcal{V}_t$ implies the marginal cost of deposits. In frictionless economies, the marginal value of assets, $\frac{\mathcal{V}_t^f}{Q_t^f}$ and $\frac{\mathcal{V}_t^c}{Q_t^c}$, are equal to the marginal cost of deposits $\mathcal{V}_t$. In this case, we have $\mu_t = 0$. However, if banks are constrained, we have

$$\mu_t^f \equiv \frac{\mathcal{V}_t^f}{Q_t^f} - \mathcal{V}_t > 0, \quad \mu_t^c \equiv \frac{\mathcal{V}_t^c}{Q_t^c} - \mathcal{V}_t > 0, \tag{21}$$

which means that the marginal value of assets is higher than the marginal cost of deposits. This implies that arbitrage is not exploited because of the constraint limiting banks' ability to acquire deposits.

Next, we consider the right-hand sides of Eqs. (16) and (17). In frictionless economies, the credit spreads ($R_k^f - (1 + r^b)$ and $R_k^f - (1 + r^b)$) are zero. However, in a model with financial frictions, the equilibrium allocation is inefficient because of credit distortion, and the credit spread is not zero (Nispi Landi, 2017; De Paoli and Paustian, 2017). From the other banks' first-order conditions (A4), (A5), and (A7) in Appendix A1, we obtain

$$\mu_t = \Theta \frac{1}{1 + (1/\lambda_{B,t})}, \tag{22}$$

where $\lambda_{B,t}$ is the Lagrange multiplier for the incentive constraint. A policymaker can change μ_t by controlling $\mathcal{T}^f$ and $\mathcal{T}^c$ in Eqs. (16) and (17), respectively. When μ_t in Eq. (22) decreases (increases), the Lagrange multiplier of the bank's incentive constraint $\lambda_{B,t}$ also decreases (increases). This implies that by employing macroprudential policies, the government can affect financial conditions and bank lending.[7]

As ϕ_t is independent of bank-specific factors, we can aggregate across banks. Therefore, from Eq. (A8), we obtain

$$N_t = \frac{1}{\phi_t}(Q_t^f S_t^f + Q_t^c S_t^c), \tag{23}$$

where the capital letters indicate the aggregate variables. From Eq. (23) and the aggregate balance sheet ($Q_t^f S_t^f + Q_t^c S_t^c = N_t + D_t$), we obtain the aggregate deposit:

$$D_t = (\phi_t - 1)N_t. \tag{24}$$

As we will argue in Section 2.4, the government returns the tax revenues from macroprudential policies to banks as a lump-sum transfer (i.e., $\zeta_t = \mathcal{T}_t^f R_{k,t}^f Q_{t-1}^f S_{t-1}^f + \mathcal{T}_t^c R_{k,t}^c Q_{t-1}^c S_{t-1}^c$). As the fraction σ of banks continue to operate in the next period, we obtain the net worth of existing banks, N_{et}, from Eq. (11) as follows:

$$N_{e,t} = \sigma(R_{k,t}^f Q_{t-1}^f S_{t-1}^f + R_{k,t}^c Q_{t-1}^c S_{t-1}^c - (1 + r_t^b)D_{t-1}). \tag{25}$$

Following previous related studies, we assume that new bankers receive a fraction $\xi/(1-\sigma)$ of the total final period assets of exiting bankers.[8] The new bank's net

[7]Eqs. (16) and (17) imply that if the incentive compatibility constraint in the banking sector does not bind, the optimal values of $\mathcal{T}_{t+1}^f$ and $\mathcal{T}_{t+1}^c$ would be zero.

[8]For a similar assumption, see Gertler and Kiyotaki (2010) and Gertler and Karadi (2011).

worth is then given by

$$N_{n,t} = \xi(R^f_{k,t}Q^f_{t-1}S^f_{t-1} + R^c_{k,t}Q^c_{t-1}S^c_{t-1}). \tag{26}$$

As the total net worth N_t is the sum of the net worth of existing banks $N_{e,t}$ and that of new banks (i.e., $N_{n,t} = N_{e,t} + N_{n,t}$), from Eqs. (25) and (26), we obtain the evolution of N_t:

$$N_t = (\sigma + \xi)(R^f_{k,t}Q^f_{t-1}S^f_{t-1} + R^c_{k,t}Q^c_{t-1}S^c_{t-1}) - \sigma(1 + r^b_t)D_{t-1}. \tag{27}$$

2.3 Non-financial firms

2.3.1 Final goods sector

The production function in the final goods sector is

$$Y^f_t = a^f_t(K^f_t)^{\alpha^f_k}(M_t)^{\alpha^f_m}(H^f_t)^{1-\alpha^f_k-\alpha^f_m}, \tag{28}$$

where Y^f_t, a^f_t, and M_t denote the output of final goods, total factor productivity in the final goods sector, and commodity inputs, respectively. The parameters α^f_k and α^f_m respectively denote capital share and commodity share. Goods producers purchase capital by obtaining funds from banks:

$$Q^f_t K^f_{t+1} = Q^f_t s^f_t. \tag{29}$$

Because we focus on financial frictions in banks, we assume no friction in non-financial firms. From the firm's first-order conditions, we have

$$w_t^f = (1 - \alpha_k^f - \alpha_m^f) a_t^f (K_t^f)^{\alpha_k^f} (M_t)^{\alpha_m^f} (H_t^f)^{-\alpha_k^f - \alpha_m^f}, \tag{30}$$

and

$$p_t^c = \alpha_m^f a_t^f (K_t^f)^{\alpha_k^f} (M_t)^{\alpha_m^f - 1} (H_t^f)^{1-\alpha_k^f - \alpha_m^f}. \tag{31}$$

As goods producers are perfectly competitive, the expected gross return on capital is

$$R_{k,t+1}^f = \frac{\alpha_k^f \frac{Y_{t+1}^f}{K_{t+1}^f} + Q_{t+1}^f (1 - \delta^f)}{Q_t^f}, \tag{32}$$

where δ^f is the depreciation rate of capital in the final goods sector.

Competitive capital producers generate new capital, subject to adjustment costs on investment. Capital producers' objective in the final goods sector is

$$\max_{I_t^f} \; E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left\{ Q_{t+i}^f I_{t+i}^f - \left[1 + f\left(\frac{I_{t+i}^f}{I_{t+i-1}^f} \right) \right] I_{t+i}^f \right\}, \tag{33}$$

where $f\left(\frac{I_{t+i}^f}{I_{t+i-1}^f}\right) I_{t+i}^f$ reflects convex adjustment costs with $f(1) = f'(1) = 0$ and $f''(I_{t+i}^f / I_{t+i-1}^f) > 0$. From the first-order condition for I_t^f, we obtain

$$Q_t^f = 1 + f\left(\frac{I_t^f}{I_{t-1}^f} \right) + \frac{I_t^f}{I_{t-1}^f} f'\left(\frac{I_t^f}{I_{t-1}^f} \right) - E_t \Lambda_{t,t+1} \left(\frac{I_{t+1}^f}{I_t^f} \right)^2 f'\left(\frac{I_{t+1}^f}{I_t^f} \right). \tag{34}$$

The capital stock in the final goods sector evolves according to

$$K_{t+1}^f = (1 - \delta^f) K_t^f + I_t^f. \tag{35}$$

2.3.2 Commodity sector

The production function in the commodity sector is

$$Y_t^c = a_t^c (K_t^c)^{\alpha_k^c} (H_t^c)^{1-\alpha_k^c}, \tag{36}$$

where Y_t^c is the output of commodities and a_t^c is total factor productivity in the commodity sector. Commodity producers purchase capital by obtaining funds from banks:

$$Q_t^c K_{t+1}^c = Q_t^c s_t^c. \tag{37}$$

From the firm's first-order conditions, we have

$$w_t^c = (1-\alpha_k^c) p_t^c a_t^c (K_t^c)^{\alpha_k^c} (H_t^c)^{-\alpha_k^c}. \tag{38}$$

The expected gross return on capital is given by

$$R_{k,t+1}^c = \frac{\alpha_k^c p_{t+1}^c \frac{Y_{t+1}^c}{K_{t+1}^c} + Q_{t+1}^c (1-\delta^c)}{Q_t^c}, \tag{39}$$

where δ^c is the depreciation rate of capital in the final goods sector. Capital producers' objective in the commodity sector is

$$\max_{I_t^c} \; E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left\{ Q_{t+i}^c I_{t+i}^c - \left[1 + f\left(\frac{I_{t+i}^c}{I_{t+i-1}^c} \right) \right] I_{t+i}^c \right\}, \tag{40}$$

where $f\left(\frac{I^c_{t+i}}{I^c_{t+i-1}}\right)I^c_{t+i}$ reflects convex adjustment costs with $f(1) = f'(1) = 0$ and $f''(I^c_{t+i}/I^c_{t+i-1}) > 0$. From the first-order condition for I^c_t, we obtain

$$Q^c_t = 1 + f\left(\frac{I^c_t}{I^c_{t-1}}\right) + \frac{I^c_t}{I^c_{t-1}} f'\left(\frac{I^c_t}{I^c_{t-1}}\right) - E_t \Lambda_{t,t+1}\left(\frac{I^c_{t+1}}{I^c_t}\right)^2 f'\left(\frac{I^c_{t+1}}{I^c_t}\right). \tag{41}$$

The capital stock in the commodity sector evolves according to

$$K^c_{t+1} = (1-\delta^c)K^c_t + I^c_t. \tag{42}$$

2.4 Government

The government's budget constraint is

$$G_t + \mathcal{Z}_t = \mathcal{T}^f_t R^f_{k,t} Q^f_{t-1} S^f_{t-1} + \mathcal{T}^c_t R^c_{k,t} Q^c_{t-1} S^c_{t-1} + T_t, \tag{43}$$

where $G_t (= G)$ is constant government spending and $\mathcal{Z}_t$ denotes the aggregate variable for the government's lump-sum transfer to a bank ζ_t. As we argue in Section 2.2, we assume that the government returns the tax revenue on macroprudential policies to banks as a lump-sum transfer (i.e., $Z_t = \mathcal{T}^f_t R^f_{k,t} Q^f_{t-1} S^f_{t-1} + \mathcal{T}^c_t R^c_{k,t} Q^c_{t-1} S^c_{t-1}$), which implies that the lump-sum tax $T_t (= G)$ is also constant. That is, the government's role reduces to a simple taxation of banks' lending and returning the collected revenues to banks.

Macroprudential policies are characterized by simple rules.

$$\mathcal{T}^f_t = \kappa_f \left[\log\left(\frac{Q^f_{t-1}}{Q^f}\right)\right], \tag{44}$$

and

$$\mathcal{T}_t^c = \kappa_c \left[\log \left(\frac{Q_{t-1}^c}{Q^c} \right) \right], \tag{45}$$

where Q^f and Q^c denote the steady-state values of Q_t^f and Q_t^c, respectively. The macroprudential policies imply that when the price of a bank's financial claims in each sector increases (decreases), the government raises (reduces) the tax rate on the bank's asset holdings in each sector.

2.5 Equilibrium

As the economy consists of two sectors and the final goods sector uses commodity inputs, GDP is given by

$$Y_t = Y_t^f + p_t^c Y_t^c - p_t^c M_t. \tag{46}$$

The trade balance is

$$TB_t = Y_t - C_t - I_t - G_t - \Gamma_t, \tag{47}$$

where $\Gamma_t \equiv f\left(\frac{I_t^f}{I_{t-1}^f}\right) I_t^f + f\left(\frac{I_t^c}{I_{t-1}^c}\right) I_t^c$ denotes the adjustment costs on investment. For the functional form of the investment adjustment cost, we adopt a quadratic function:

$$f\left(\frac{I_t^f}{I_{t-1}^f}\right) = \frac{\iota^f}{2}\left(\frac{I_t^f}{I_{t-1}^f} - 1\right)^2, \;\; f\left(\frac{I_t^c}{I_{t-1}^c}\right) = \frac{\iota^c}{2}\left(\frac{I_t^c}{I_{t-1}^c} - 1\right)^2. \tag{48}$$

From Eq. (47), the foreign debt position B_t evolves according to

$$B_t = (1 + r_t^w) B_{t-1} - TB_t. \tag{49}$$

The world commodity price p_t^c evolves according to the following exogenous shock process:

$$\ln\left(\frac{p_t^c}{p^c}\right) = \rho \log\left(\frac{p_{t-1}^c}{p^c}\right) + \epsilon_t^{p^c}, \;\; \epsilon_t^{p^c} \sim i.i.d.\mathcal{N}(0, \sigma_{p^c}^2). \tag{50}$$

The equilibrium of this economy is a set of stationary stochastic processes $\{$ r_t^w, C_t, H_t^f, H_t^c, r_t^b, λ_t, $\Lambda_{t,t+1}$, μ_t, $\mathcal{V}_t$, Ω_t, ϕ_t, S_t^f, S_t^c, D_t, N_t, Y_t^f, K_{t+1}^f, w_t^f, M_t, $R_{k,t+1}^f$, Q_t^f, I_t^f, Y_t^c, K_{t+1}^c, w_t^c, $R_{k,t+1}^c$, Q_t^c, I_t^c, $\mathcal{T}_t^f$, $\mathcal{T}_t^c$, Y_t, TB_t, B_t $\}_{t=0}^{\infty}$ satisfying Eqs.(3)-(8), (13), (16)-(20), (23), (24), (27)-(32), (34)-(39), (41), (42), (44)-(47), and (49) (combined with the related equations for other variables), given $G_t = G$, exogenous stochastic processes p_t^c, and initial values for D_{-1}, N_{-1}, K_0^f, K_0^c, S_{-1}^f, S_{-1}^c, and B_{-1}.

2.6 Calibration

For calibration, we set the main parameters to ensure consistency with Mongolia's macro data. For the other conventional parameters, we follow the related literature and adopt commonly used values.

We set the steady-state ratio of net exports of commodities relative to GDP, TB^c/Y, to 0.2086, obtained from Mongolia's data.[9] We set the commodity input share in final goods production, α_m^f, to 0.2982 to match the target of TB^c/Y. We set the steady-state level of the (quarterly and real) deposit rate, r^b, to 0.0121, calculated from Mongolia's average (real) deposit rate (1.21%).[10] In accordance with the deposit rate r^b, we set the (quarterly) discount factor β to 0.9880. We set the steady-state levels of (quarterly, real, and gross) lending rates R_k^f and R_k^c

[9] We obtain this number using International Financial Statistics (IFS) and the World Integrated Trade Solution (WITS) database. The sample period is 2005Q1-2018Q3.

[10] We obtain this number from IFS. The sample period is 1998Q1-2022Q3.

to 1.0405, calculated from Mongolia's average real lending rate (0.0405%).[11] To match r^b, R_k^f, and R_k^c obtained from Mongolia's data, we set the banker's fraction of divertable assets, Θ, the survival rate of banks, σ, and the transfers to entering bankers, ξ, to 0.504, 0.8, and 0.0188, respectively. We set the sensitivity of interest spreads to commodity prices χ to 0.3052, as estimated for Mongolia by Kitano (2021).[12] We set the steady-state ratio of net exports relative to GDP, TB/Y, to -0.0678, obtained from Mongolia's data.[13] Targeting TB/Y, we choose the steady-state level of foreign debt B. We set the steady-state ratio of government expenditure to GDP, G/Y, to 0.1291, obtained from Mongolia's data.[14]

Regarding the other parameters not mentioned above, we choose standard values from the related literature. The inverse of the intertemporal elasticity of substitution γ is set to 2 (as in Aguiar and Gopinath (2007)). Following Drechsel and Tenreyro (2018), we set the curvature parameters on labor (η^f and η^c) to 1.6. We set the labor coefficient θ to generate steady-state labor hours ($H \equiv H^f + H^c$) of 1/3. Following Shousha (2016), we set capital share in production (α_k^f and α_k^c) to 0.32. In line with Garcia-Cicco et al. (2010), we set the depreciation rate of capital (δ^f and δ^c) to 0.1255/4. We set the parameters for the adjustment costs on investment ι^f and ι^c to 1.5. Following Aguiar and Gopinath (2007), we set the coefficient on the interest rate premium term (ψ) to 0.001. The steady-state leverage ratio ϕ is set to 4.5, which is an approximate average of leverages between the corporate and banking sectors.[15] For the parameters on commodity price shocks, we set the

[11] We obtain this number from IFS. The sample period is 1998Q1-2022Q3.

[12] Table 1 in Kitano (2021).

[13] We obtain this number from IFS. The sample period is 2005Q1-2018Q3.

[14] We obtain this number from IFS. The sample period is 2005Q1-2018Q3.

[15] The ratio of assets to equity in the corporate sector is around 2, whereas leverage ratios in the banking sector are greater than 5 in emerging countries (IMF, 2015,2017,2018). We follow the argument of Akinci and Queralto (2018), which uses a rough average of leverage across different

persistence ρ and standard deviation σ_{p^c} to 0.9 and 0.02, respectively, to roughly match the direction and size of the empirical impulse response of Mongolia's trade balance (ratio to GDP) obtained in Kitano (2021).

sectors.

Table 1: Parameterization

	Description	Value
Parameters related to households		
γ	Inverse of intertemporal elasticity of substitution	2
β	Discount factor	0.9880
θ	Labor coefficient	2.15
η^f, η^c	Curvature parameter on labor	1.6
Production parameters		
α_k^f, α_k^c	Capital share in production	0.32
α_m^f	Commodity input share in final goods production	0.2982
δ^f, δ^c	Depreciation rate of capital	0.1255/4
ι^f, ι^c	Parameter for adjustment cost on investment	1.5
Parameters related to open economies		
TB^c/Y	Steady-state ratio of net exports of commodities relative to GDP	0.2086
TB/Y	Steady-state ratio of net exports relative to GDP	-0.0678
ψ	Parameter for country-specific interest rate premium	0.001
χ	Sensitivity of interest rate spreads to commodity prices	0.3052
Parameters related to banks		
R_k^f, R_k^c	Steady-state (real and gross) lending rate	1.0405
r^b	Steady-state (real) deposit rate	0.0121
Θ	Fraction of divertable assets	0.504
ξ	Transfer to entering bankers	0.0188
σ	Survival rate of banks	0.8
ϕ	Steady-state leverage ratio	4.5
Other parameters		
G/Y	Steady-state ratio of government expenditure to GDP	0.1291
ρ	Persistence: commodity price shock	0.9
σ_{p^c}	Standard deviation: commodity price shock	0.02

3 Numerical experiment results

This section presents numerical experiments that shed light on the role of macroprudential policies for commodity-exporting economies. As mentioned in Section 1, commodity price shocks have a sizable contribution to the business cycle fluctuations in emerging economies (e.g., Drechsel and Tenreyro, 2018). Therefore, we consider commodity price shocks to be exogenous shocks in our numerical experiments.

Figure 3 shows the impulse responses of output, consumption, investment, and trade balance (ratio to GDP) in response to a commodity price shock. Using structural vector auto-regression (SVAR), Kitano (2021) shows that a positive commodity price shock causes a negative response in the trade balance and positive responses in output, consumption, and investment. The directions of the impulse responses in Figure 3 are consistent with those for Mongolia in Kitano (2021). This implies that our model is consistent with the empirical evidence on Mongolia's economy.

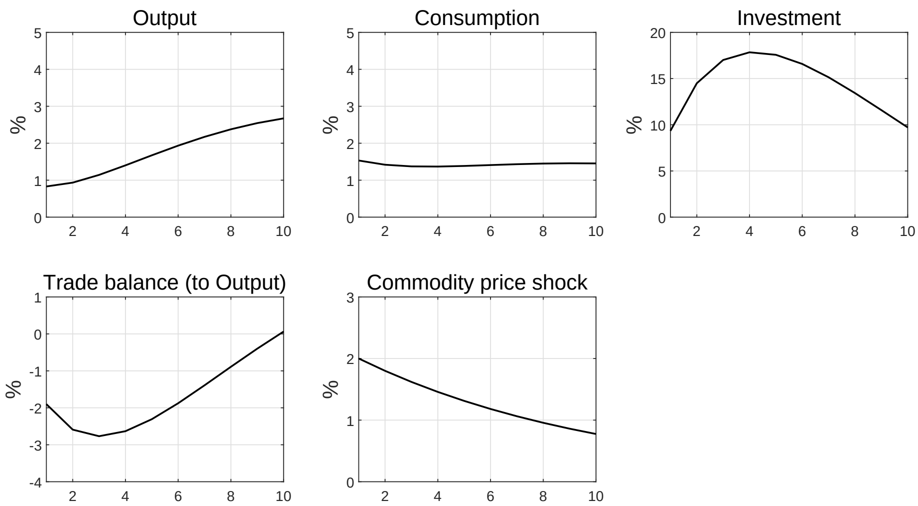


Figure 3: Impulse responses of output, consumption, investment, and trade balance (ratio to GDP) in response to a positive commodity price shock

3.1 Employing macroprudential policies in each sector

Figure 4 shows the impulse responses with and without macroprudential policy on bank lending to the commodity sector. The solid curve represents the impulse responses with the macroprudential policy rule of $\kappa_c = 0.01$ (not necessarily optimal), whereas the dotted curve represents those without it. In addition to total consumption, output, investment, and trade balance, Figure 4 includes each sector's output, investment, and trade balance. When the commodity price increases, the commodity sector's output also increases (rises above zero). By contrast, the final goods sector's output initially decreases (declines below zero) because it uses commodities as inputs to produce final goods. However, over time, the final goods sector's output recovers and expands as the boom caused by a positive commodity price shock outweighs the negative effect. When the commodity price rises, the real interest rate falls owing to the negative relationship between commodity prices and the interest rate spread (in Eq.(3)). A fall in the real interest rate raises investment in both the commodity and final goods sectors. The final goods trade balance becomes negative because of the investment boom. As the negative trade balance of final goods exceeds the positive trade balance of commodities, the trade balance of the economy as a whole is negative.

As Figure 4 shows, macroprudential policies on bank lending to the commodity sector stabilize total output, consumption, and trade balance. The commodity sector is the main channel of stabilization. Macroprudential policies on bank lending to the commodity sector curb the commodity sector's investment and output, while the effects on the other sector's investment and output are negligible. However, it has almost no effect on the real interest rate. As a result, total consumption is almost unaffected. This implies that, while macroprudential policies on bank lending to the commodity sector are effective in controlling the total economy, the policy distortion effect seems modest.

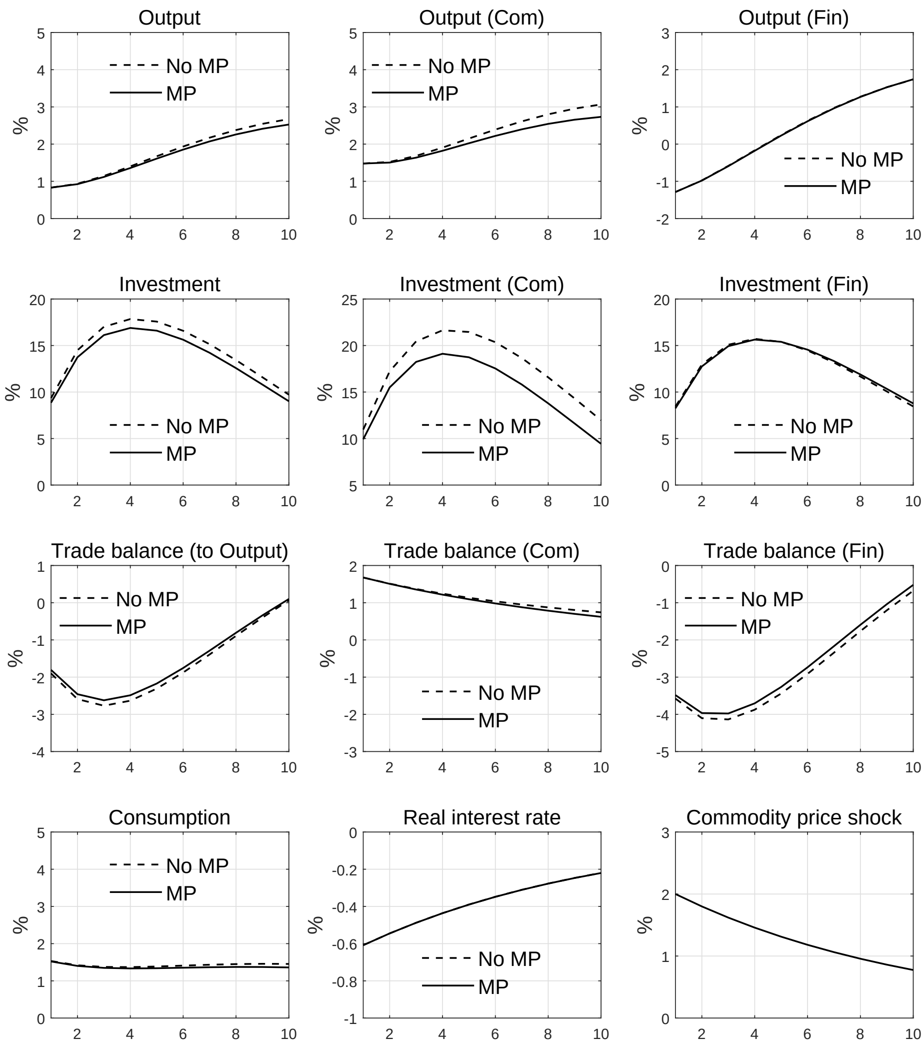


Figure 4: Impulse responses: Macroprudential policy (MP) on bank lending to the commodity sector

Figure 5 shows the impulse responses with and without macroprudential policy on bank lending to the final goods sector. The solid curve represents the impulse responses with the macroprudential policy rule of $\kappa_f = 0.01$ (not necessarily optimal), whereas the dotted curve represents those without it. Figure 5 also includes each sector's output, investment, and trade balance, as well as the total output, investment, and trade balance. As in the case of the commodity sector in Figure 4, macroprudential policy on bank lending to the final goods sector also stabilizes the total output, consumption, and trade balance. In contrast to the commodity sector case in Figure 4, macroprudential policies on bank lending to the final goods sector curb its investment and output, whereas the effects on the other sector's investment and output are negligible in Figure 5. Similar to the commodity sector case, macroprudential policies in the final goods sector scarcely affect the real interest rate and total consumption. This implies that, while macroprudential policies on bank lending to the final goods sector are effective in controlling the total economy, the policy distortion effect seems modest.

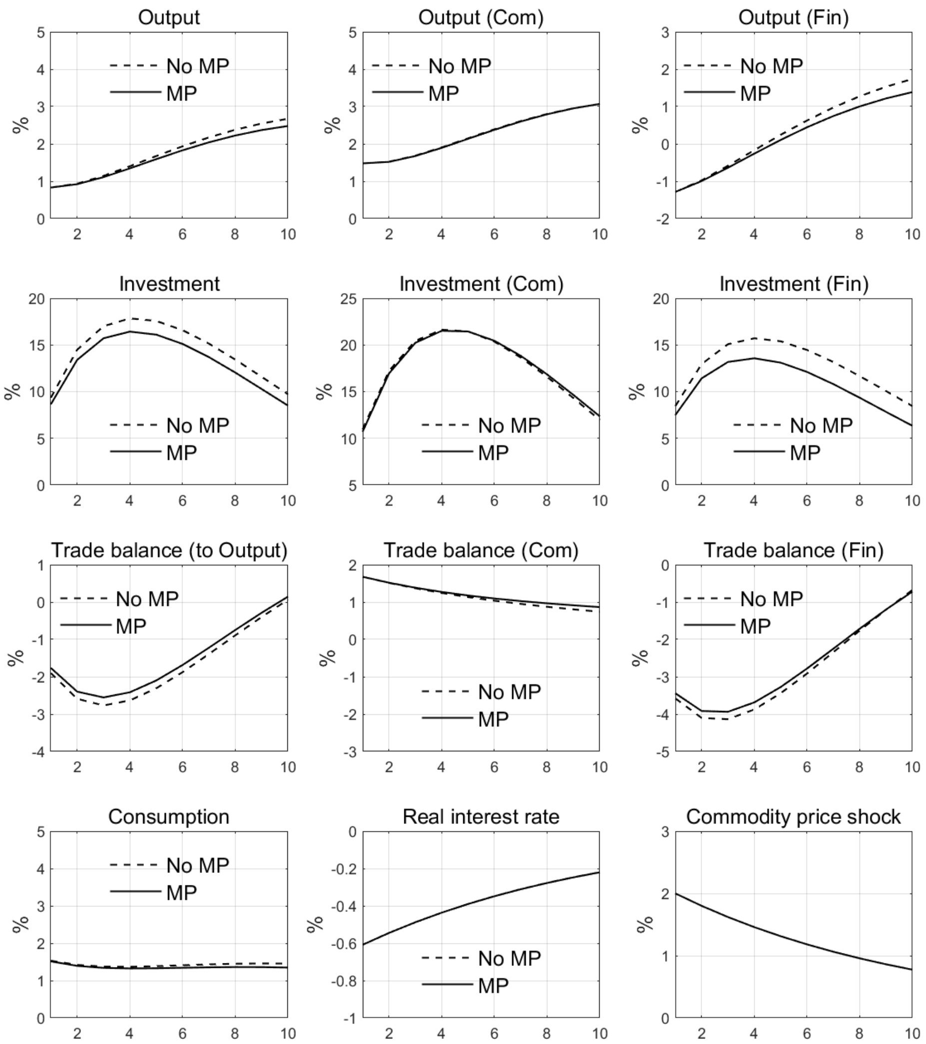


Figure 5: Impulse responses: Macroprudential policy (MP) on bank lending to the final goods sector

Next, we examine the welfare-improving effects of macroprudential policies on bank lending in each sector. For policy evaluation, we compute the welfare level associated with a particular policy rule and compare it with that in the no-policy case. We perform a second-order approximation of the model using the perturbation method in Schmitt-Grohé and Uribe (2004).[16] As in Schmitt-Grohé and Uribe (2006), we consider the expected welfare conditional on the initial state, that is, the non-stochastic steady state.

The welfare associated with a particular value of κ_f in Eq.(44) and/or κ_c in Eq.(45) conditional on the non-stochastic steady states is defined as

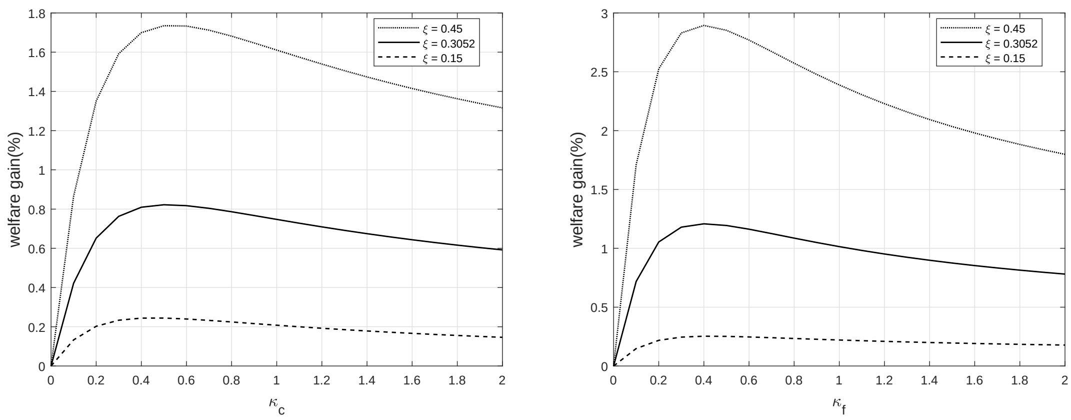
$$\mathcal{W}_0 \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, H_t^f, H_t^c) = E_0 \sum_{t=0}^{\infty} \beta^t U((1+\epsilon_i)C, H^f, H^c), \tag{51}$$

where C, H^f, and H^c are their non-stochastic steady states. We evaluate the welfare-improving effect of macroprudential policies on bank lending by comparing the value of ϵ_i associated with each value of κ_f and/or κ_c with that in the no-policy case (i.e., $\kappa_f = \kappa_c = 0$).

Figures 6a and 6b show the welfare curves associated with different values of κ_c and κ_f, respectively. In Figures 6a and 6b, the horizontal axes are κ_c and κ_f, and the vertical axes represent the welfare gain (%), which is the difference between the value of ϵ_i associated with each value of κ_c and κ_f and that in the no-policy case. We show the welfare curves corresponding to three different degrees of commodity-price elasticity of spread ξ: the bold dotted curve ($\xi = 0.15$), the bold curve ($\xi = 0.3052$), and the thin dotted curve ($\xi = 0.45$). Each welfare curve

[16] Kim and Kim (2003) show that second-order solutions are necessary as conventional linearization may generate spurious welfare reversals when long-run distortions exist in the model. We conduct the second-order computation using Dynare. See Adjemian et al. (2011) for further details.

is hump-shaped, and there exists an optimal value of κ_c (κ_f) that achieves the maximum welfare gain in each case. By comparing the three cases, we can see that the maximum welfare gain is higher when ξ is larger. A higher value of ξ indicates a higher sensitivity of the interest spread to commodity prices. Figures 6a and 6b show that macroprudential policies on bank lending to each sector are more welfare enhancing as the elasticity of spread to commodity prices ξ is higher.

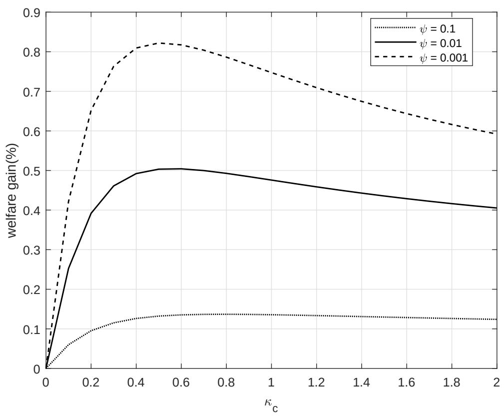


(a) commodity sector

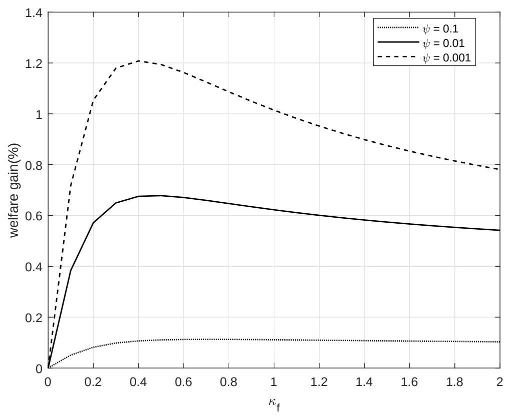
(b) final goods sector

Figure 6: Welfare gain of macroprudential policies on bank lending to each sector under different values of $\xi (= 0.15, 0.3052, \text{ and } 0.45)$: the elasticity of spread to commodity prices

Figures 7a and 7b show the welfare curves corresponding to three different degrees of debt elasticity of spread ψ: the bold dotted curve ($\psi = 0.001$), the bold curve ($\psi = 0.01$), and the thin dotted curve ($\psi = 0.1$). Each welfare curve is hump-shaped, and there exists an optimal value of κ_c (κ_f) that achieves the maximum welfare gain in each case. A lower value of ψ indicates a lower sensitivity of the interest spread to debt. A lower sensitivity of the spread to debt implies that the degree of stationarity of foreign debt is weaker, and the economy is more volatile when it encounters shocks. Therefore, macroprudential policies are more effective when ψ is lower.



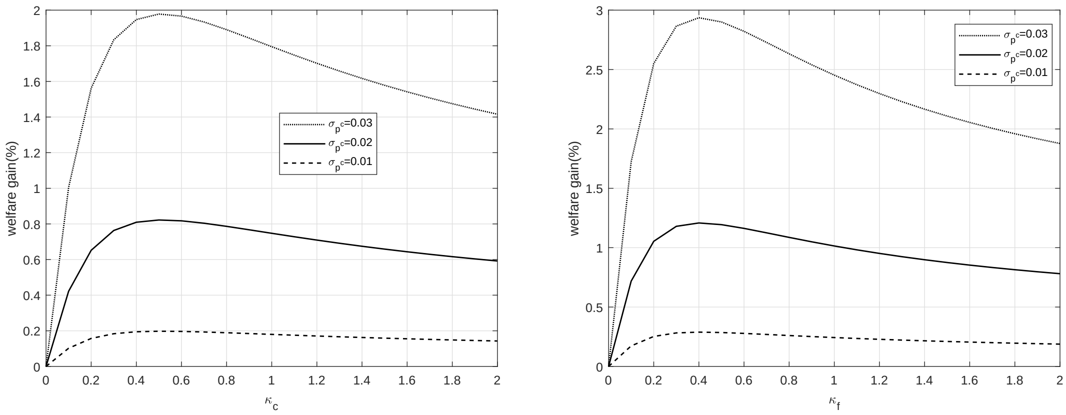
(a) commodity sector



(b) final goods sector

Figure 7: Welfare gain of macroprudential policies on bank lending to each sector under different values of $\psi(= 0.001, 0.01,$ and $0.1)$: the sensitivity of interest spread to debt

Figures 8a and 8b show the welfare curves corresponding to three different sizes of commodity price shocks σ_{p^c}: the bold dotted curve ($\sigma_{p^c} = 0.01$), the bold curve ($\sigma_{p^c} = 0.02$), and the thin dotted curve ($\sigma_{p^c} = 0.03$). Each welfare curve is hump-shaped and the optimal value of κ_c (κ_f) achieves the maximum welfare gain. By comparing the three cases, we can see that the maximum welfare gain is higher when σ_{p^c} is larger. A higher value of σ_{p^c} indicates a larger commodity price shock. A larger commodity price shock implies greater economic volatility. Therefore, Figures 8a and 8b imply that both macroprudential policies are more effective when the economy suffers from greater volatility in commodity price shocks.



(a) commodity sector

(b) final goods sector

Figure 8: Welfare gain of macroprudential policies on bank lending to each sector under different values of $\sigma_{p^c}(= 0.01, 0.02, \text{ and } 0.03)$: commodity price shocks

3.2 Employing macroprudential policies in both sectors

The previous section examined the welfare-improving effect of macroprudential policies on bank lending to the final goods and commodity sectors separately. This section examines the case in which policymakers employ both macroprudential policies on bank lending to the final goods and commodity sectors.

Figure 9 plots the welfare gains from combining different values of κ_c and κ_f for the three different degrees of commodity-price elasticity of spread ξ. In Figure 9, the left, middle, and right panels show the cases of $\xi = 0.15$, $\xi = 0.3052$, and $\xi = 0.45$, respectively. In each panel, the z-axis plots the welfare gain levels achieved by combining different values of κ_c and κ_f, and the x- and y-axes plot κ_f and κ_c. As the three-dimensional graph is mountain-shaped, Figure 9 implies that it would be better to employ macroprudential policies in both sectors simultaneously rather than employ macroprudential policies in each sector separately, and that the optimal levels of κ_f and κ_c achieve the maximum level of welfare gains in each case. Comparing the z-axis in the three cases of ξ shows that the maximum welfare gain increases as the value ξ increases, which is consistent with the results shown in Figures 6a and 6b.

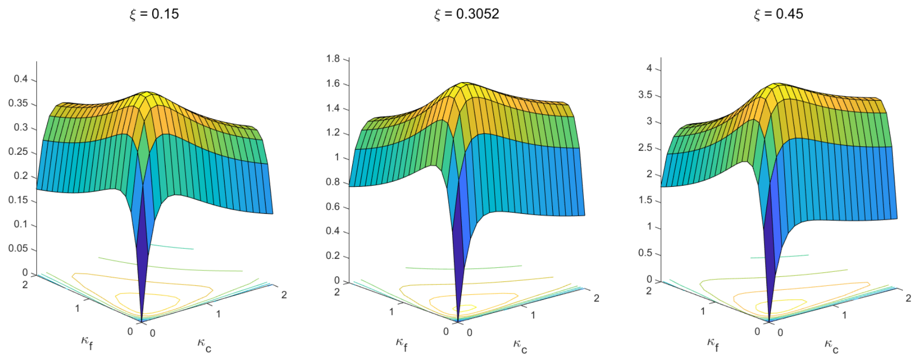


Figure 9: Welfare gain of macroprudential policies on bank lending to both sectors under different values of $\xi(= 0.15, 0.3052$, and $0.45)$: the elasticity of spread to commodity prices

Figure 10 plots the welfare gains from combining different values of κ_c and κ_f for the three different degrees of debt elasticity of spread ψ. In Figure 10, the left, middle, and right panels show the cases of $\psi = 0.0001$, $\psi = 0.001$, and $\psi = 0.01$, respectively. As the three-dimensional graph is mountain-shaped, Figure 10 implies that it is more desirable to employ macroprudential policies in both sectors simultaneously rather than employ macroprudential policies in each sector separately. In other words, by choosing the optimal levels of κ_f and κ_c, policymakers can achieve the maximum welfare gain in each case. A comparison of the z-axes for the three cases of ψ reveals that the maximum welfare gain increases as the value ψ decreases. These results are consistent with the cases of macroprudential policies in each sector, as shown in Figures 7a and 7b.

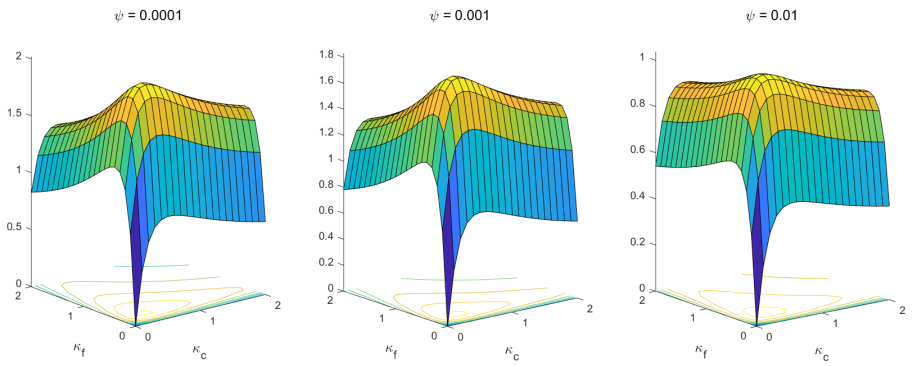


Figure 10: Welfare gain of macroprudential policies on bank lending to both sectors under different values of $\psi(= 0.0001, 0.001,$ and $0.01)$: the sensitivity of interest spread to debt

Figure 11 plots the maximum welfare gains from combining different values of κ_c and κ_f for the three different sizes of commodity price shocks σ_{p^c}. In Figure 11, the left, middle, and right panels show the cases of $\sigma_{p^c} = 0.01$, $\sigma_{p^c} = 0.02$, and $\sigma_{p^c} = 0.03$, respectively. The mountain-shaped graph implies that it is more desirable to employ macroprudential policies in both sectors simultaneously rather than employ macroprudential policies in each sector separately. Comparing the maximum welfare gain in each case, which is achieved by choosing the optimal levels of κ_f and κ_c, we know that as the size of the commodity price shocks σ_{p^c} increases, the maximum welfare gain increases.

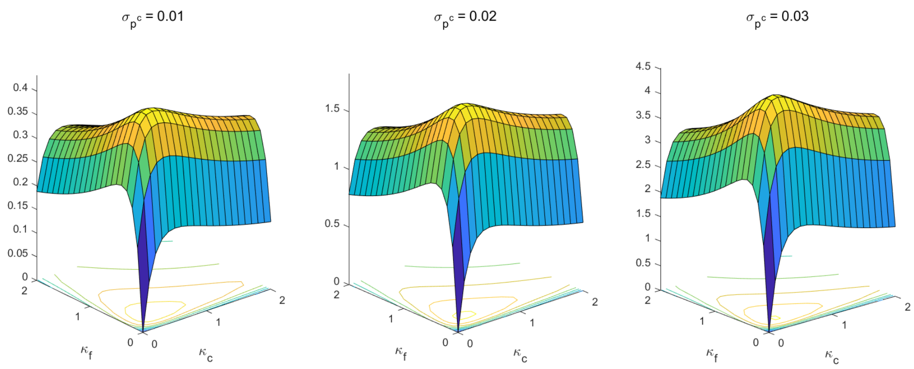


Figure 11: Welfare gain of macroprudential policies on bank lending to both sectors under different values of $\sigma_{p^c}(= 0.01, 0.02, \text{and } 0.03)$: commodity price shocks

4 Conclusion

Fluctuating commodity prices have a serious impact on commodity-exporting countries. This study examined the effectiveness of macroprudential policies in commodity-exporting countries. By comparing the impulse responses and welfare levels under macroprudential policies on bank lending to the final goods and commodity sectors, we show that both macroprudential policies are more effective when the elasticity of spread to commodity prices and the size of exogenous shocks are large. Regarding the debt elasticity of spread, both macroprudential policies are more effective when it is small. In addition, we show that it is more desirable to employ macroprudential policies in both sectors simultaneously rather than employ macroprudential policies in each sector separately. Kinda et al. (2018) empirically find that countries implementing macroprudential policies are better able to cope with the damaging effect of negative shocks to commodity prices. Using a small open DSGE model augmented with the empirically estimated key parameters for Mongolia's economy, our theoretical study confirms Kinda et al. (2018)'s empirical finding that macroprudential policies are an effective policy tool for commodity-exporting countries vulnerable to international commodity price shocks.

As we argue in Section 1, few studies have examined the effect of macroprudential policies in commodity-exporting countries using DSGE models. Although González et al. (2015) and Villca (2022) are exceptions, they assume that commodity production evolves exogenously and that there is no optimization problem in the commodity sector. In contrast, commodity production is determined endogenously in our model. González et al. (2015) mention that, "[o]ur quantitative model could be extended along several dimensions. A promising one could be to consider the case of an endogenous oil extraction process in which oil producers respond to economic incentives, like price changes" (page 23) in their conclusion. Thus, this study accomplishes the task suggested by González et al. (2015). Our model setting with endogenous commodity production makes it possible to analyze macroprudential policies in the final goods and commodity sectors separately in emerging economies facing volatile world commodity price changes.

Appendix

A1 Derivation of equations in Section 2.2

We denote the bank's maximized objective as $V_t(s_t^f, s_t^c, d_t)$ given an asset and liability configuration (s_t^f, s_t^c, d_t). The bank's value in period $t-1$ satisfies the Bellman equation:

$$V_t(s_t^f, s_t^c, d_t) = E_t \Lambda_{t,t+1} \left\{ (1-\sigma) n_{t+1} + \sigma \max_{s_{t+1}^f, s_{t+1}^c} V_t(s_{t+1}^f, s_{t+1}^c, d_{t+1}) \right\}. \tag{A1}$$

We propose and verify that the value function is linear in s_t^f, s_t^c, and d_t.

$$V_t(s_t^f, s_t^c, d_t) = \mathcal{V}_t^f s_t^f + \mathcal{V}_t^c s_t^c - \mathcal{V}_t d_t, \tag{A2}$$

where $\mathcal{V}_t^f$ is the marginal value of assets in the final goods sector, $\mathcal{V}_t^c$ is the marginal value of assets in the commodity sector, and $\mathcal{V}_t$ is the marginal cost of deposits.

Substituting Eq. (10) into (A2), we obtain

$$
\begin{aligned}
V_t(s_t^f, s_t^c, n_t) &= \mathcal{V}_t^f s_t^f + \mathcal{V}_t^c s_t^c - \mathcal{V}_t(Q_t^f s_t^f + Q_t^c s_t^c - n_t), \\
&= \mu_t^f Q_t^f s_t^f + \mu_t^c Q_t^c s_t^c + \mathcal{V}_t n_t,
\end{aligned} \tag{A3}
$$

where $\mu_t^f \equiv \frac{\mathcal{V}_t^f}{Q_t^f} - \mathcal{V}_t$, and $\mu_t^c \equiv \frac{\mathcal{V}_t^c}{Q_t^c} - \mathcal{V}_t$.

Maximizing the value function (A3) subject to the incentive constraint (14) yields the following first-order conditions.

$$
(1 + \lambda_{B,t})\mu_t^f = \Theta\lambda_{B,t}, \tag{A4}
$$

$$
(1 + \lambda_{B,t})\mu_t^c = \Theta\lambda_{B,t}, \tag{A5}
$$

and

$$
(\Theta - \mu_t^f)Q_t^f s_t^f + (\Theta - \mu_t^c)Q_t^c s_t^c = \mathcal{V}_t n_t, \tag{A6}
$$

where $\lambda_{B,t}$ is the Lagrange multiplier for the incentive constraint (14).

Combining Eqs. (A4) and (A5), we obtain

$$
\mu_t^f = \mu_t^c \equiv \mu_t. \tag{A7}
$$

Defining ϕ_t, we can rewrite (A6) as

$$
Q_t^f s_t^f + Q_t^c s_t^c = \phi_t n_t, \tag{A8}
$$

with

$$
\phi_t \equiv \frac{\mathcal{V}_t}{\Theta - \mu_t}. \tag{A9}
$$

Substituting Eq. (A8) into (A3) and using (A7), we can rewrite the value function with net worth n_t as follows:

$$V_t(s_t^f, s_t^c, n_t) = (\phi_t \mu_t + \mathcal{V}_t) n_t. \tag{A10}$$

Substituting Eqs. (A10) and (11) into (A1) and comparing it with the results from substituting (10) into (A3), we verify that the value function is linear in (s_t^f, s_t^c, d_t) if μ_t and $\mathcal{V}_t$ satisfy

$$\mu_t = E_t \Lambda_{t,t+1} \Omega_{t+1} [(1 - \mathcal{T}_t^f) R_{k,t+1}^f - (1 + r_{t+1}^b)], \tag{A11}$$

$$\mu_t = E_t \Lambda_{t,t+1} \Omega_{t+1} [(1 - \mathcal{T}_t^c) R_{k,t+1}^c - (1 + r_{t+1}^b)], \tag{A12}$$

and

$$\mathcal{V}_t = E_t \Lambda_{t,t+1} \Omega_{t+1} (1 + r_{t+1}^b), \tag{A13}$$

where

$$\Omega_t \equiv (1 - \sigma) + \sigma(\phi_t \mu_t + \mathcal{V}_t). \tag{A14}$$

Eqs. (A3), (A8), (A9), (A11), (A12), (A13), and (A14) correspond to Eqs. (15), (23), (20), (16), (17), (18), and (19) in the main text, respectively.

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