# Commodities as Collateral*

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June 30, 2015

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**Keywords**: commodity, collateral, financialization, theory of storage, capital control

**JEL Codes**: G12, Q02

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This paper proposes and tests a theory of using commodities as collateral for financing. Under capital control and collateral constraint, financial investors import commodities and pledge them as collateral to earn a risk premium. The collateral demand for commodities increases commodity prices globally; it also increases commodity futures risk premium in the importing country but reduces that in the exporting country. Evidence from eight commodities in China and developed markets supports the theoretical predictions, and the effects are economically large. Our theory and evidence complement the theory of storage and provide new insights on the financialization of commodity markets.

# 1 Introduction

This paper proposes and tests a theory of using commodities as collateral for financing. If risk premium in one country is sufficiently higher than that in international markets, and if capital control prevents the flow of "arbitrage" capital, then financial investors would import commodities to the high-risk-premium country and use them as collateral to earn a risk premium. As a vehicle to circumvent capital control, the financing (rather than production) use of commodities has significant impacts on prices and risk premium in global commodity markets.

Studying the collateral use of commodities is important for at least two reasons. First, it is a new and unexplored channel for the financalization of commodity markets. A number of recent studies present evidence that financial investors affect the price dynamics in commodity markets (see Tang and Xiong (2012), Singleton (2014), Henderson, Pearson and Wang (2015), Cheng, Kirilenko and Xiong (2014), and Baker (2014), among others). In these studies financial investors trade commodity futures, derivatives, and structured products, but not the underlying *physical* commodities. By contrast, investors using commodities as collateral necessarily deal with physical commodities; hence, the collateral channel is a new contribution to this literature.

Second, and more broadly, the collateral use of commodities concretely illustrates an unintended consequence of capital control. Commodities are imported to circumvent capital control, just like off-balance sheet vehicles are set up to take advantage of certain accounting rules before the global financial crisis (asset-backed commercial paper is one major example). Both forms of "shadow banking" lead to market distortions. Moreover, collateral demands of commodities can create a spillover to the real economy by affecting the prices of production assets.

The best market to study the collateral use of commodities is China. China is the world's second largest economy and the leading consumer and importer of commodities, accounting for about 40% of global copper consumption and steel consumption.[1] China's financial market, however, is immature and underdeveloped. Small- and medium-sized firms that have high expected returns but do not have sufficient collateral often find it difficult to obtain financing on an unsecured basis, leading to a high unsecured interest rate faced by these firms.[2] Moreover, because of capital control,[3]

[1]For copper statistics, see International Copper Study Group (2013). For steel statistics, see World Steel Association (2013).

[2]For example, the Wenzhou Private Finance Index shows that the recent interest rates on private borrowing is about 20% in the Wenzhou metropolitan area, which an entrepreneurial hub in the southeast of China. See http://www.wzmjjddj.com/news/bencandy.php?fid=97&id=1997 (Chinese language website).

[3]The capital inflows to China's financial markets from abroad are controlled by the "Qualified Foreign Institu-

this funding gap cannot be filled by moving financial capital across the Chinese border. In a manner to be described shortly, the combination of collateral constraints and capital control in China makes it very attractive to import commodities as collateral, as such imports are not counted as capital flow. Industry estimates that in 2014 about \$109 billion FX loans in China are backed by commodities as collateral, equivalent to about 31% of China's total short-term FX loans and 14% of China's total FX loans (see Yuan, Layton, Currie, and Courvalin (2014)).[4]

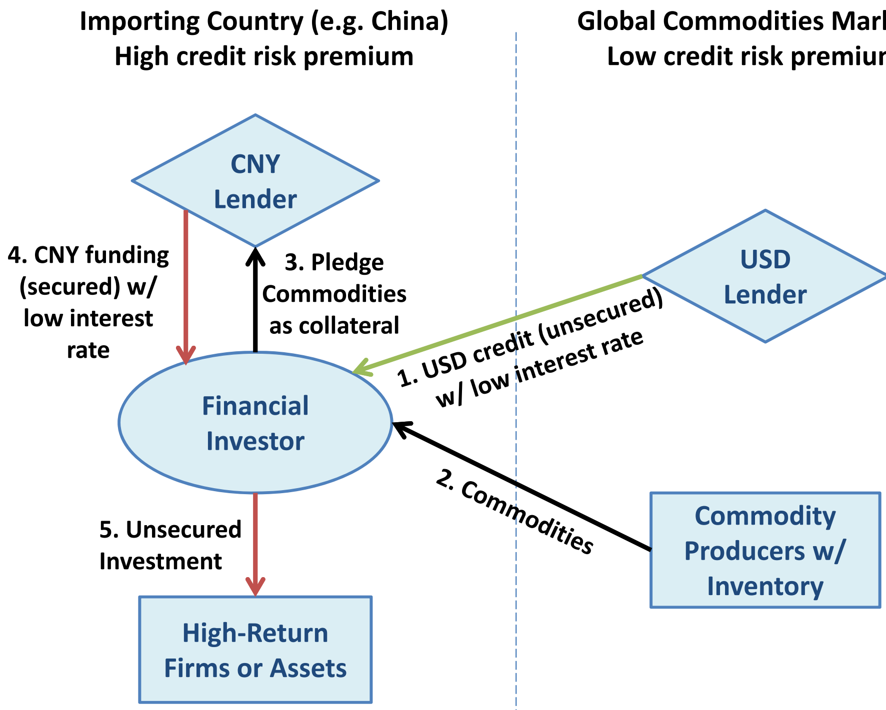
We present a simple two-period, two-country model that formalizes the causes and effects of financing using commodity as collateral. In the model, a representative fundamental consumer of commodities in the importing country, say China, buys commodities from a representative producer in the exporting country. Both countries have futures markets in which agents can share commodity price risk. Due to capital control, financial markets of the two countries are segmented, an extreme form of "capital immobility" (see Duffie (2010) and Duffie and Strulovici (2012)). Trades of commodities, however, are not restricted by capital control as commodities are input for fundamental consumption.

When the importing country has a sufficiently high unsecured interest rate relative to the exporting country, the collateral demand for commodities endogenously emerges. Financial investors in the importing country conduct a series of commodity and financial transactions illustrated in Figure 1 (more institutional details are provided in Section 2). At time 0 they borrow USD broad through trade credit at the relatively low unsecured interest rate and buy commodities, such as copper and aluminum. These commodities are imported and then pledged in the domestic market to get secured, low-interest loans, which are subsequently lent to firms that have higher expected returns but cannot obtain financing elsewhere due to collateral constraint. In period 1 all borrowing and lending are unwound, and the collateral commodity is sold to the fundamental consumer. The financial investor can further use the futures

tional Investor" (QFII) program, managed by the State Administration of Foreign Exchange (SAFE). SAFE grants the QFII status to selected foreign institutions, which can then invest in China's financial markets. Each QFII has a quota on the maximum amount it can invest. According to Xinhua News Agency, as of June 2013, the overall quota for all QFIIs is \$80 billion, among which the combined quota of \$41.76 billion has been allocated to 229 foreign institutions. Conversely, capital outflows from China to international financial markets are controlled by the "Qualified Domestic Institutional Investor" (QDII) program, also managed by SAFE. Each QDII can invest in international financial markets, up to a specific quota.

[4]Take copper for example. The Economic Observer (2012) estimates that 90% of copper stored in the tariff-free zone in Shanghai are for financing purposes, with the total amount more than 500 thousand tons. Shanghai Metals Market, a research firm, estimates that between 400 and 600 thousand tons of copper has been used for financing in China in 2013. To put these estimates into perspective, a half million tons of copper are approximately 5.7% of China's annual copper consumption and 2.4% of world consumption in 2012.

Figure 1: A typical process of commodity-based financing




market in the importing country to hedge the commodity price risk.

The model reveals that the collateral demand for commodities has a number of important implications, relative to the case with only fundamental demand. For example, the collateral demand increases concurrent commodity prices in both the importing and exporting countries. The model also predicts that risk premium for buying commodity futures increases in the importing country but decreases in the exporting country. Lastly, because collateral demands tend to raise inventory and convenience yield simultaneously in the importing country, the inventory-convenience yield relation should become significantly less negative in that country.

We test the model predictions in the markets for eight commodities, including four metals, copper, zinc, aluminum, and gold, and four nonmetals, soybean, corn, fuel oil, and natural rubber. The importing country is taken to be China and the exporting country is taken to be developed markets (e.g. US, UK, Japan). Our sample consists of weekly observations of prices and inventories from October 13, 2006 to November 14, 2014. We test how the collateral demands for commoditie affect (i) commodity prices, (ii) futures risk premium, and (iii) the relation between inventory and convenience yield. In each test, we conduct eight commodity-by-commodity regressions and two panel regressions for the metal group and nonmetal group. Our theory also suggests that the predicted effects should be more evident in the metal group since they have higher value-to-bulk ratios and are easier to store and ship than other commodities.

A main challenge in conducting the tests is the measurement of collateral demand. Although it would be desirable to directly observe how much commodity is pledged as collateral, such data could not be obtained due to the opacity of this market. Instead, we construct an indirect, theory-motivated empirical measure. Recall that the attractiveness of importing commodities as collateral requires two frictions. First, the unsecured interest rate in China is sufficiently higher than that in developed markets. Second, this interest-rate spread cannot be eliminated by moving financial capital because of China's capital control. As a proxy for the unsecured interest rate spread, we use the difference between the Shanghai Interbank Offered Rate (Shibor) in CNY and London Interbank Offered Rate (Libor) in USD. As a proxy for the tightness of capital control, we use the the violation of the covered interest rate parity (CIP) in the USDCNY exchange rate. What is important for us are the time variations in these proxies rather than their levels. Our overall proxy for the collateral demand for commodities is the product of the Shibor-Libor spread and the violation of CIP. Since the financial crisis this measure is predominantly positive and highly time-varying, and it is essentially uncorrelated with China's economic growth.

Empirical tests support our theory. In the first test, we find that a higher collateral demand for commodities significantly increases the spot commodity prices in China and in developed markets for the metal group. The economic magnitude is large. In our sample the collateral-demand-for-commodities measure has an approximate peak-to-trough range of 0.135. A fluctuation of this magnitude corresponds to a 15.0% increase in copper prices, a 13.6% increase in zinc price, and a 11.9% increase in aluminum price, all measured by dollar prices on the London Metal Exchange.

In the second test, we find that a higher collateral demand for commodities significantly increases the futures risk premium in China but reduces that in developed markets for the metal group. The statistical significance is much stronger in the panel regression than in the individual regressions. The coefficients are also economically larger for China than for developed markets.

In both the price and futures risk premium tests, we detect no statistically significant effect on the nonmetal group. This is intuitive because agricultural commodities and oil are bulky and relatively expensive to store and ship, hence not ideal collateral.

In the third test, we find that a higher collateral demand for commodities makes the inventory-convenience yield relation significantly less negative in China. This test distinguishes our theory from the theory of storage, which predicts that inventory and convenience yield move in opposite directions. In our theory of commodity collateral, inventory and convenience yield move in the same direction in China. We find evidence supporting both, complementary theories.

One salient conclusion from this paper is that high commodities prices do not necessarily imply strong fundamental demand. Rather, high prices could be due to strong collateral demand, driven by financial frictions and capital control in China, the largest commodity importer and consumer. This implication resonates with Sockin and Xiong (2014)'s insight that, with informational frictions, large financial inflows to commodity markets can be misread as a favorable signal about global economic growth. Information frictions and collateral demand can both potentially explain why prices of certain commodities (e.g. copper) reached record highs in 2008 when the global economic fundamentals turned out to be weak.

While the institutional settings of this paper is modeled after China, the essential friction, i.e. capital control, is more widespread. Since the global financial crisis, for example, various forms of capital control have been imposed in Brazil, India, South Korea, Indonesia, Ukraine, and Iceland, among others (see IMF (2012)). To the extent that capital control is now regarded as part of the policy toolkit for prudential regulation (see Rogoff (2002) and Ostry et al. (2010)), our results can be viewed as yet another reminder that endogenous responses to capital control can cause unintended market distortions.

We caution that our current analysis does not lead to definitive welfare conclusions. On the one hand, we show that the collateral demand for commodity can partly crowd out the real demand and obscure the informativeness of commodity prices about global economic growth. On the other hand, pledging commodities as collateral can relax funding constraints and reduce inefficiency. Adding to this tradeoff are the many costs and benefits of imposing capital controls in the first place (see Ostry et al. (2010)). Analyzing the net welfare implication, therefore, requires a much richer and more general equilibrium model, which we leave for future research.

This paper contributes to the emerging literature on the financialization of commodity markets. A common theme in this literature so far is whether financial investors' trading activity in commodity futures, derivatives, or structured products move underlying commodity prices. Tang and Xiong (2012) document that the growth of index investment into commodities coincides with a large increase in the correlation of various commodity prices. Basak and Pavlova (2013) show that this elevated correlation can arise in a model in which institutional investors care about outperforming a commodity index. Singleton (2014) and Cheng, Kirilenko and Xiong (2014) link the positions of various trader groups in futures markets to commodity price dynamics. Knittel and Pindyck (2013) and Hamilton and Wu (2015) conclude that index investing in commodity futures does not lead to significant inventory accumulation or predictability of futures returns. Henderson, Pearson and Wang (2015) show that the hedging activities by issuers of commodity-linked notes affect commodity futures and spot prices. Baker (2014) shows through a theoretical model that easier access to commodity futures by households can affect excess returns and volatility of commodities, but cannot account for large price increases. Different from these studies, an essential element of our theory and evidence is the collateral use of *physical* commodities, which is a novel contribution to the literature.

Our theory and empirical findings are complementary to the classical theory of storage (see Working (1939), Telser (1949), Brennan (1958), Routledge, Seppi and Spatt (2000), Pindyck (2001), and Gorton, Hayashi and Rouwenhorst (2012), among others). For example, while the theory of storage predicts a negative relation between convenience yield and inventory, our model predicts that the collateral demands for commodity raise inventory and convenience yield simultaneously, a positive relation. Moreover, collateral demands result in a high total inventory and a high commodity price simultaneously. This is again opposite to the prediction from the theory of storage that a higher inventory indicates the abundance of commodity and hence a lower price.

# 2 Commodities as Collateral in Practice

In this section we discuss the institutional details of importing commodities as collateral for financing, as well as the underlying financial frictions and risks.

A typical commodity financing transaction consists of a few steps.[5] First, a Chinese importing firm signs a contract to buy commodity from an overseas firm. As is standard in international trade, the importing firm uses the purchase contract to apply for a letter of credit from a domestic or foreign bank. The letter of credit is typically granted in dollars at the US dollar interest rate and guarantees that the seller will be paid by the bank.[6] In order to obtain the credit, the importing firm needs to pay a margin, which is about 20% to 30% of the loan amount. The maturity of the letter of credit varies and is often between three to six months. For example, if the letter of credit

[5] For additional overviews of the institutional arrangements of commodity financing, see Yuan, Layton and Currie (2013), Garvey and Shaw (2014), and Fu (2014).

[6] Banks that involve in commodity trade financing include BNP Paribas, Crédit Agricole, ING, Société Générale, JPMorgan, Citigroup, Standard Chartered, and HSBC, among others. See "Banks return to commodities finance", by Javier Blas and Ajay Makan, Financial Times, February 5, 2013.

is granted for six months, the importing firm needs to pay back the USD loan plus interest after six months. The importer can sell futures contracts in China to hedge the price risk of holding the commodity.

Second, the importer ships commodity to bonded warehouses in China's ports and obtain the warehouse receipts. Note that at this stage the commodity stored in bonded warehouses has not yet entered the Chinese customs, and the importer does not have to pay the associated duties yet. The warehouse receipt is subsequently provided to a domestic bank as collateral to obtain a CNY loan. A typical loan haircut is 30%, that is, the amount of the CNY loan is 70% of the market value of the commodity. Typically, the interest on the secured CNY loan is significantly lower than the expected return in other asset markets in China, such as short-term lending to small businesses. Effectively, the importer uses the commodity collateral to capture the spread between the secured and unsecured CNY funding rates in China.

Third, after three or six months, the commodity importer receives the unsecured return from its CNY investments and then sells the commodity stored in bonded warehouse in China's ports. The importer also closes its futures position. The proceeds of commodity sale and investment returns in its CNY investment are used to pay for the domestic bank loan in CNY (with relatively low CNY interest rates) and the foreign bank for the letter of credit (with relatively low USD interest rate). This completes a typical commodity financing transaction. The financial frictions in China are sufficiently large for this series of trades to make a positive expected return. Just like in carry trades in currency market, this expected return should not be viewed as an arbitrage but a risk premium for taking credit risk in China.

There are some variations of the above procedure. For instance, at the maturity of the CNY loan, the importing firm may re-sell the commodity in bonded warehouse to an overseas firm, again outside Chinese customs, and subsequently repeat the commodity financing procedure. This way, subsequent "importing" of commodities does not involve physical shipments because the inventories are local. Thus, each ton of imported commodity can be used to obtain financing multiple times.

Another alternative arrangement involves the immediate sale of the imported commodity to the Chinese spot markets. The proceeds of the sale in CNY is then invested to obtain higher expected returns than the USD interest rates. A main difference of this procedure is that the commodity has to enter customs and incur the associated duties, and repeating this financing arrangement involves importing additional commodity, instead of recycling existing commodity in bonded warehouses.

As we discussed in the introduction, the financial frictions that give rise to commodity-based financing are twofold. First, China's financial markets are immature, and many small firms cannot obtain credit for lack of eligible collateral. Second, capital flows in and out of China are strictly controlled. The combination of collateral constraint and capital control leads to a relatively large credit risk premium in China, compared to developed economies. These frictions also lead to the development of "shadow banking," i.e., lending by non-bank institutions to borrowers who need credit. Commodity-based financing is a major example.

As in other forms of shadow banking, a primary risk involved in commodity-based financing is credit risk. For example, in the third step of commodity-based financing described above, if its CNY investments default or have low realized returns, the commodity importer may not have enough financial resources to cover its USD unsecured loan and its CNY secured loan. The banks that provided secured credit in this process can also suffer losses if commodity prices drop by more than the haircut level.

To concretely illustrate the large scale of commodity-based financing and the associated risks, Figure 2 shows the reaction of copper prices on the London Metal Exchange (LME) to two China-specific events in the first half of 2014.

On Wednesday, March 5, 2014, Shanghai Chaori Solar, a Chinese solar equipment producer, said it would not be able to pay the interest of $14.7 million on its corporate bonds that is due that Friday.[7] Following this announcement, the global benchmark copper price traded on LME tumbled by more than 8.5% over a week, from $7102.5/ton on March 5 to $6498/ton on March 12. Although the Chaori default is relatively small, it was the first ever Chinese corporate bond default, which likely led to a reassessment of corporate default risk in China. A higher default risk reduces the risk-adjusted return for importing commodities and using them as collateral.[8]

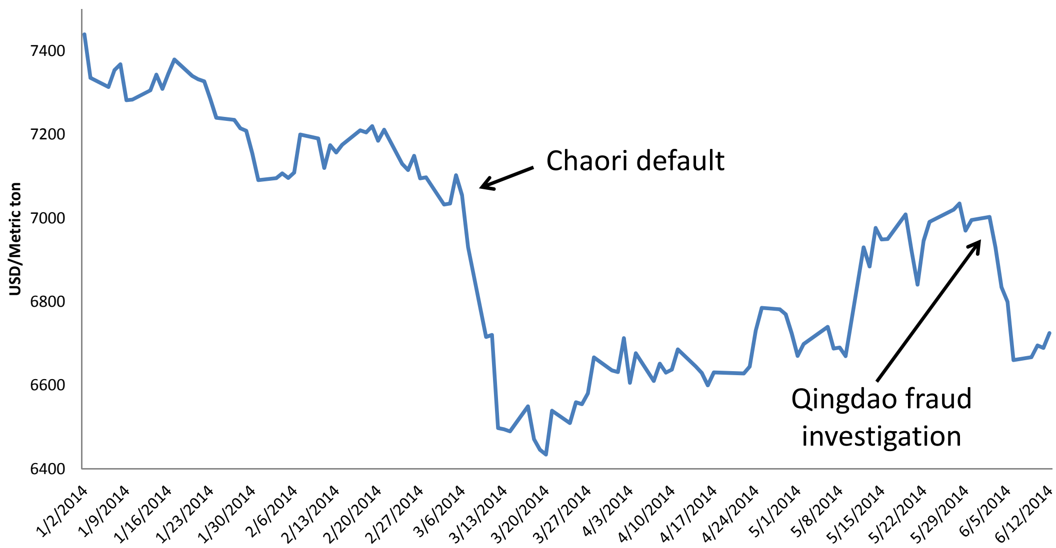
The second event is the probe by Chinese authorities of alleged frauds in the port of Qingdao (in northern China) that the same commodities like copper have been pledged to multiple banks to get multiple loans.[9] LME copper prices dropped by about 4% from $6930/ton on June 3 to $6660.5/ton on June 6. Since multiple pledging of collateral is likely to reduce the recovery value of commodity-backed loans in default, lenders may impose tighter lending requirements such as a higher haircut. This, in turn, reduces the attractiveness of importing commodity as collateral and associated commodity

[7]See "China's Chaori Solar poised for landmark bond default," by Gabriel Wildau and Umesh Desai, Reuters, March 5, 2014.

[8]See "Copper futures fall by daily limit," by Xan Rice, Jamie Smyth, and Lucy Hornby, Financial Times, March 12, 2014 and "China Angst Slams Prices for Copper," by Ira Iosebashvili and Tatyana Shumsky, Wall Street Journals, March 10, 2014.

[9]See "Standard Bank starts probe of potential irregularities at China port," by Susan Thomas, Reuters, June 4, 2014.

Figure 2: LME copper prices around two China-specific events




prices.[10]

# 3 A Model of Commodities as Collateral

In this section we present a simple model of commodities as collateral.

There are two periods, $t \in \{0, 1\}$, and a single commodity. There is a representative commodity exporting country and a representative commodity importing country. The exporting country has a commodity supplier and a speculator. The importing country has a commodity supplier, a fundamental user of commodity for production, and a financial investor who imports commodity as collateral.

For simplicity, we assume that commodities in both countries are priced in US dollars. (Effectively, FX exposures are hedged.[11]) Moreover, the commodity importing country, which is modeled after China, imposes capital controls, so that its financial market and the financial market of the exporting country are segregated.

For ease of reference, Appendix A lists the exogenous and endogenous variables we use in this model. We use the superscript "e" (resp. "i") to denote quantities and prices in the exporting (resp. importing) country.

[10]See "Worry plagues commodity finance trade after Chinese metals probe," by Fayen Wong and Manalo Serapio Jr, Reuters, June 8, 2014.

[11]If commodities are priced in the local currency in the importing country and in USD in the international market, the hedging contract involves buying USD forward against the local currency.

The rest of this section describes the model components in detail. The last subsection, Section 3.8, discusses our modeling choices and potential alternative approaches. Equilibrium solutions and implications are presented in Section 4 and Section 5.

## 3.1 Supplier in the Exporting Country

We directly model the net supply in the exporting country. Our model in the exporting country is largely adopted from Acharya, Lochstoer and Ramadorai (2012). Let $I_t^e$ and $G_t^e$ be the aggregate commodity inventory and production, respectively. Let $\delta \in (0, 1)$ be the cost of storage; that is, the producer can store $I$ units of the commodity at $t-1$ and receive $(1-\delta)\, I$ units at $t$. We also assume that the production schedule $(G_0^e, G_1^e)$ are fixed ex ante and common knowledge. (Effectively, changing production in the short term is very costly.) The inventory $I_0^e$, however, is a choice variable of the producer. Given the choice of inventory $I_0^e$, the commodity sales in period 0 and period 1 are, respectively,

$$Q_0^e = G_0^e - I_0^e, \tag{1}$$

$$Q_1^e = G_1^e + (1-\delta) I_0^e. \tag{2}$$

In addition to selling the commodity in the spot market, the commodity supplier shorts $h_p^e$ futures contracts in the exporting country at the price of $F^e$ to hedge its inventory and production.

Therefore, the terminal wealth of the producer is

$$W_p^e = S_0^e(G_0^e - I_0^e)(1+r^e) + S_1^e(G_1^e + (1-\delta)I_0^e) - h_p^e(S_1^e - F^e), \tag{3}$$

where $r^e$ is the secured interest rate in the exporting country and $S_t^e$ is the commodity spot price in period $t$. We emphasize that $S_1^e$ is a random variable. As we elaborate shortly, $S_1^e$ is determined by the stochastic demand of the importing country in period 1. We denote by $\sigma_S^e$ the volatility (standard deviation) of $S_1^e$.

The commodity producer has a mean-variance utility of the form

$$E[W_p^e] - \frac{\gamma_p^e}{2}\text{Var}[W_p^e]. \tag{4}$$

Substituting in the expression of $W_p^e$, we see that the producer solves the problem

$$\max_{\{I_0^e, h_p^e\}} S_0^e \left(G_0^e - I_0^e\right)(1+r^e) + E\left[S_1^e((1-\delta) I_0^e + G_1^e) - h_p^e \left(S_1^e - F^e\right)\right]$$
$$- \frac{\gamma_p^e}{2} \text{Var}\left[S_1^e((1-\delta) I_0^e + G_1^e) - h_p^e \left(S_1^e - F^e\right)\right] \tag{5}$$
$$\text{subject to: } I_0^e \geq 0.$$

We denote by $\lambda \geq 0$ the Lagrange multiplier associated with the inventory constraint $I_0^e \geq 0$. Taking the first-order condition with respect to the inventory $I_0^e$ and futures position $h_p^e$, we get

$$I_0^e = \frac{E\left[S_1^e\right](1-\delta) - S_0^e(1+r^e) + \lambda}{\gamma_p^e \left(\sigma_S^e\right)^2 (1-\delta)^2} + \frac{h_p^e - G_1^e}{(1-\delta)}, \tag{6}$$

$$h_p^e = I_0^e(1-\delta) + G_1^e - \frac{E\left[S_1^e - F^e\right]}{\gamma_p^e \left(\sigma_S^e\right)^2}. \tag{7}$$

If $I_0^e > 0$, $\lambda = 0$. If $I_0^e = 0$, $\lambda > 0$. The endogenous $\lambda$ affects the convenience yield of holding the commodity.

## 3.2 Speculator in the Exporting Country

The speculators only trade futures in the exporting country, and their futures position is denoted by $h_s^e$. They have mean-variance utility and solve the following optimization problem

$$\max_{h_s^e} E\left[h_s^e \left(S_1^e - F^e\right)\right] - \frac{\gamma_s^e}{2} \text{Var}\left[h_s^e \left(S_1^e - F^e\right)\right]. \tag{8}$$

The solution is

$$h_s^e = \frac{E\left[S_1^e - F^e\right]}{\gamma_s^e \left(\sigma_S^e\right)^2}. \tag{9}$$

## 3.3 Market Clearing in the Exporting Country

From (6) and (7) we obtain

$$\frac{S_0^e - F^e}{S_0^e} = \frac{\lambda}{S_0^e(1-\delta)} - \frac{r^e + \delta}{1-\delta}. \tag{10}$$

Thus, the futures price in the exporting country is

$$F^e = \frac{S_0^e(1+r^e) - \lambda}{1-\delta}, \tag{11}$$

By the futures market clearing, $h_p^e = h_s^e$, we have

$$E\left[S_1^e - F^e\right] = \frac{\gamma_s^e \gamma_p^e}{\gamma_s^e + \gamma_p^e} \left(\sigma_S^e\right)^2 \left[I_0^e \left(1-\delta\right) + G_1^e\right]. \tag{12}$$

Since $F^e$ is solved, the above equation has two unknowns, $E[S_1^e]$ and $I_0^e$. These two variables cannot be determined by variables in the exporting country alone; rather, we need the demand from the importing country, which we turn to now.

## 3.4 Producer in the Importing Country

Since the commodity supply in the importing country is not our main focus, we simply assume that the commodity production in the importing country is given by $Q_t^i = a + bS_t^i$, where $a < 0$ and $b > 0$ are commonly known constants. For simplicity, we will restrict attention to parameters such that the commodity producer in the importing country does not wish to carry inventory from time 0 and time 1. The explicit condition is provided shortly. Relaxing this parameter restriction does not change the qualitative nature of the results.

## 3.5 Fundamental Demander in the Importing Country

We model the "fundamental demander" in the importing country as a consumer who uses commodity as input to produce final goods. At time $t$, the fundamental demander has a linearly decreasing marginal profit per unit of commodity input,

$$k_t - S_t^i - lD_t^i, \tag{13}$$

where $k_t$ is a random variable, $l$ is a constant, and $D_t^i$ is the amount of commodity input used at time $t$. At time 0, $k_0$ is commonly known, but $k_1$ is unobservable and is normally distributed $N\left(\mu_k, \sigma_k^i\right)$. This stochastic $k_1$ can be interpreted as the "fundamental shock" to the economy of the importing country, only realized at time 1. All players in our model have symmetric information and the same probability distribution about $k_1$.

The fundamental demander has three endogenous choices at time 0: the amount of commodities to import, $D_{0,f}^i$, the amount of commodities to buy in domestic market, $D_{0,d}^i$, and the amount of futures contracts to trade in the local market, $h_d^i$. The shipment of one unit of commodity across the two countries incurs the cost $h > 0$. For simplicity, shipment is instantaneous, that is, commodity purchased in the exporting country at time $t$ can be used in the importing country at time $t$ as well.

The fundamental demander's terminal wealth in period 1 that is derived from his production and trading activity in period 0 is

$$\begin{aligned} W_{d,0}^i = & D_{0,f}^i \left[k_0 - (S_0^e + h) - l\left(D_{0,f}^i + D_{0,d}^i\right)\right]\left(1 + r^i\right) \\ & + D_{0,d}^i \left[k_0 - S_0^i - l\left(D_{0,f}^i + D_{0,d}^i\right)\right]\left(1 + r^i\right) + h_d^i\left(S_1^i - F^i\right), \end{aligned} \tag{14}$$

where $r^i$ is the secured interest rate in the importing country, and the first and second terms are the fundamental demander's total profits of using foreign and domestic commodity supplies, respectively.

The fundamental demander has the mean-variance preference with parameter $\gamma_d^i$ and solves[12]

$$\max_{\left\{D_{0,d}^i, D_{0,f}^i, h_d^i\right\}} E[W_{d,0}^i] - \frac{\gamma_d^i}{2}\text{Var}[W_{d,0}^i], \tag{15}$$

$$\text{Subject to: } D_{0,f}^i \geq 0. \tag{16}$$

The solution to the above problem is

$$D_{0,f}^i = \frac{k_0 - (S_0^e + h)}{2l} - D_{0,d}^i + \eta, \tag{17}$$

$$D_{0,d}^i = \frac{k_0 - S_0^i}{2l} - D_{0,f}^i, \tag{18}$$

$$h_d^i = \frac{E\left[S_1^i - F^i\right]}{\gamma_d^i \left(\sigma_S^i\right)^2}, \tag{19}$$

where $\sigma_S^i$ is the volatility of $S_1^i$ and $\eta$ is the Lagrange multiplier associated with the constraint (16). If $D_{0,f}^i = 0$, i.e. the fundamental demander only buys commodity locally, then $\eta > 0$. If $D_{0,f}^i > 0$, then $\eta = 0$.

Similarly, we can solve the fundamental demander's problem at time 1. We denote by $D_{1,f}^i$ and $D_{1,d}^i$ the demands for foreign and domestic commodity, respectively. The terminal wealth of the fundamental demander is

$$W_{d,1}^i = D_{1,f}^i \left[k_1 - (S_1^e + h) - l(D_{1,f}^i + D_{1,d}^i)\right] + D_{1,d}^i \left[k_1 - S_1^i - l(D_{1,f}^i + D_{1,d}^i)\right]. \tag{20}$$

Since the fundamental shock $k_1$ is realized and becomes common knowledge at time 1,

[12] Because $k_1$ is an exogenous variable, the mean and variance of the fundamental demander's period-1 wealth that comes from his period-1 production activity are not affected by his period-0 strategy, $(D_{0,f}^i, D_{0,d}^i, h_d^i)$. Thus, we can solve his optimal strategies period by period.

the fundamental demander solves

$$\max_{\{D^i_{1,d}, D^i_{1,f}\}} W^i_{d,1}. \tag{21}$$

The solution is

$$D^i_{1,d} = \frac{k_1 - S^i_1}{2l} - D^i_{1,f}, \tag{22}$$

$$D^i_{1,f} = \frac{k_1 - (S^e_1 + h)}{2l} - D^i_{1,d}. \tag{23}$$

## 3.6 Financial Demander in the Importing Country

The financial demander in the importing country imports commodity not for production, but to use it as collateral to get secured financing at rate $r^i$ and lend unsecured at rate $R^i > r^i$. (Without loss of generality, the interest rates $R^i$ and $r^i$ are after adjusting for the haircut imposed on the loan.) In other words, the commodity is imported as a means to capture the unsecured-secured spread, or risk premium, of $R^i - r^i$. The financial demander must first borrow unsecured in the exporting country at the rate $R^e$ to pay for the costs of commodity and shipping. Since borrowing and lending take one period, this trade must be completed at time 0. The expected time-1 profit of importing one unit of collateral commodity at time 0 is

$$S^i_0(R^i - r^i) + (1 - \delta)\, E[S^i_1] - (S^e_0 + h)\,(1 + R^e). \tag{24}$$

The three terms capture, respectively, the expected profit of borrowing $S^i_0$ at rate $r^i$ and lending at rate $R^i$, the proceeds from selling the remaining $(1 - \delta)$ commodity at time 1, and the payment of the unsecured loan at rate $R^e$. We later specify explicit conditions under which the expected profit of importing commodity as collateral is positive. We denote by $C^i_0$ the amount of commodity imported for collateral purposes at time 0.

We emphasize that these "collateral commodities" must be imported for this trade to be viable. If the financial demander were to use domestic commodity, he must first pay the unsecured rate $R^i$, defeating the purpose of lending at $R^i$.

The financial demander also uses futures contract to hedge his position. We denote by $h^i_c$ his futures position at time 0.

The financial demander's terminal wealth at time 1 is

$$W_f^i = C_0^i \left[S_0^i(R^i - r^i) + (1-\delta)\, S_1^i - (S_0^e + h)\,(1+R^e)\right] - h_c^i(S_1^i - F^i). \tag{25}$$

The financial demander has a mean-variance utility function with parameter $\gamma_c^i$. At time 0, he solves the problem

$$\max_{\{C_0^i, h_c^i\}} E[W_f^i] - \frac{\gamma_c^i}{2}\mathrm{Var}[W_f^i]. \tag{26}$$

where the variance comes from the uncertainty about $S_1^i$.

Solving for the optimal $C_0^i$ and $h_c^i$, we get

$$C_0^i = \frac{S_0^i(R^i - r^i) + (1-\delta)\, E\left[S_1^i\right] - (S_0^e + h)\,(1+R^e)}{\gamma_c^i \left(\sigma_S^i\right)^2 (1-\delta)^2} + \frac{h_c^i}{1-\delta}, \tag{27}$$

$$h_c^i = -\frac{E\left[S_1^i - F^i\right]}{\gamma_c^i \left(\sigma_S^i\right)^2} + C_0^i\,(1-\delta)\,. \tag{28}$$

### 3.7 Market Clearing in the Importing Country

From (17) and (18), we get

$$S_0^i = S_0^e + h - 2l\eta. \tag{29}$$

Recall that $\eta$ is the Lagrange multiplier associated with $D_{0,f}^i \geq 0$; $\eta > 0$ whenever $D_{0,f}^i = 0$. Thus, if all commodity imports are made for financing purposes, the commodity price in the importing country is lower than that in the exporting country after adjusting for shipping costs.

From (22) and (23) we get

$$S_1^i = S_1^e + h.$$

By the market-clearing condition of the futures market, $h_d^i = h_c^i$, we have

$$C_0^i = \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right) \frac{E\left[S_1^i - F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}. \tag{30}$$

For parameters considered in this paper, $C_0^i \geq 0$. Cases in which $C_0^i = 0$ are identical to the benchmark case without the collateral use of commodities. From (27) and (28), we can solve the futures price in the importing country,

$$\begin{aligned} F^i &= \frac{(S_0^e + h)(1 + R^e)}{1 - \delta} - \frac{S_0^i (R^i - r^i)}{1 - \delta} \\ &= \frac{1 + r^i - (R^i - R^e)}{1 - \delta} S_0^i + \frac{2l(1 + R^e)}{1 - \delta} \eta. \end{aligned} \tag{31}$$

### 3.8 Discussion of Model Setup

In this subsection we make a couple of remarks on our modeling choices.

First, in our model the futures markets of the two countries are segregated; investors cannot trade futures contracts across two countries. This assumption is a direct consequence of capital control of the importing country, modeled after China. If investors were able to circumvent capital controls and participate directly in financial markets in both countries, importing commodities as collateral would be unnecessary. Indeed, in the model we can show that if the collateral demanders can also trade futures contracts in the exporting country, they would not import commodities. Thus, capital control and the effective segregation of financial markets is an essential friction in the model and in reality.

Second, we have used a two-period model, which may seemingly suggest that the unwinding of the commodity collateral trade in period 1 is mechanical. One could argue that in a multiple-period or infinite-horizon model, financial players would import commodities as collateral in every period. While this concern is reasonable, importing commodities as collateral cannot continue forever. Because commodities are imported to take advantage of the credit risk premium in China, a large amount of collateral commodities would relax small firms' funding constraint in China and start to reduce the risk premium. Once the risk premium becomes sufficiently small, commodity importing would become unattractive and finally stop (given its cost). We would expect that a more general long-horizon model, in which unsecured interest rates are endogenous of the amount of commodity collateral, would deliver qualitatively similar results as our two-period model.

## 4 Equilibrium

In this section we characterize the equilibrium prices and quantities. We first consider the equilibrium in which demanders of collateral commodities participate in the market. Then, we consider the equilibrium without collateral demands for commodities.

## 4.1 Equilibrium with Demand for Collateral Commodity

Putting together the market-clearing conditions from the previous section, we have the following proposition.

**Proposition 1.** *Suppose that collateral demanders of commodities participate in the market. In equilibrium, the spot prices* $(S_0^e, S_1^e, S_0^i, S_1^i)$*, the inventory* $I_0^e$ *in the exporting country, and the fundamental demands* $(D_{0,d}^i, D_{1,d}^i)$ *are given by the solution to the following system of equations:*

$$
\begin{aligned}
a + bS_0^i &= D_{0,d}^i, && (32)\\
G_0^e - I_0^e &= D_{0,f}^i + C_0^i \\
&= \left[\frac{k_0 - (S_0^e + h)}{2l} - D_{0,d}^i + \eta\right] + \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right) \frac{E\left[S_1^i - F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}, && (33)\\
E\left[S_1^e - F^e\right] &= \frac{\gamma_s^e \gamma_p^e}{\gamma_s^e + \gamma_p^e} \left(\sigma_S^e\right)^2 \left[I_0^e(1-\delta) + G_1^e\right], && (34)\\
D_{1,d}^i &= a + bS_1^i + \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right) \frac{E\left[S_1^i - F^i\right]}{\left(\sigma_S^i\right)^2}, && (35)\\
I_0^e(1-\delta) + G_1^e &= D_{1,f}^i \\
&= \frac{k_1 - (S_1^e + h)}{2l} - D_{1,d}^i, && (36)\\
S_1^i &= S_1^e + h, && (37)\\
S_0^i &= S_0^e + h - 2l\eta, && (38)
\end{aligned}
$$

*where*

$$
\begin{aligned}
F^e &= \frac{S_0^e(1+r^e) - \lambda}{1-\delta}, && (39)\\
F^i &= \frac{(S_0^e + h)(1+R^e) - S_0^i(R^i - r^i)}{1-\delta}. && (40)
\end{aligned}
$$

*The two Lagrange multipliers* $(\lambda, \eta)$ *satisfy:*

$$
\begin{aligned}
&\text{if } I_0^e = 0,\ \lambda > 0,\\
&\text{if } I_0^e > 0,\ \lambda = 0;
\end{aligned}
$$

*and*

$$\text{if } D^i_{0,f} = 0,\ \eta = D^i_{0,d} - \frac{k_0 - (S^e_0 + h)}{2l} > 0,$$
$$\text{if } D^i_{0,f} > 0,\ \eta = 0.$$

*The solution of spot prices and inventories are:*

$$S^i_0 = \frac{\left[\begin{array}{c} \frac{(1-\delta)(k_0-2al)}{2l} + mq + n(q - h + zh) - [G^e_0(1-\delta) + G^e_1] \\ + \frac{n}{1-\delta}\lambda - 2l(om + zn)\eta \end{array}\right]}{v + (1-\delta+w)m + (1-\delta+z)n}, \tag{41}$$

$$S^e_0 = S^i_0 - h + 2l\eta. \tag{42}$$

$$S^i_1 = \frac{1}{2bl+1}[k_1 - 2al + (1-\delta)(k_0 - 2al) - 2l((1-\delta)G^e_0 + G^e_1)] - (1-\delta)S^i_0, \tag{43}$$

$$S^e_1 = S^i_1 - h, \tag{44}$$

$$I^e_0 = \frac{1}{1-\delta}\left[n(q - h + zh) - (1-\delta+z)nS^i_0 - G^e_1 - 2nlz\eta + \frac{n\lambda}{1-\delta}\right], \tag{45}$$

*where the constants* $(n, m, q, o, z, v, w)$ *are defined in the Appendix B.1. The equilibrium demands* $(C^i_0, D^i_{0,d}, D^i_{1,d}, D^i_{0,f}, D^i_{1,f})$ *are calculated from* (32)–(36).

Depending on whether the two Lagrange multipliers $\lambda$ and $\eta$ are zero or positive, there are four cases of equilibrium:

Case 1. $\lambda = 0$ and $\eta = 0$, i.e., $I^e_0 > 0$ and $D^i_{0,f} > 0$. In this case, the exporting country does not experience a stockout, and the fundamental demander uses both domestic and foreign commodity.

Case 2. $\lambda = 0$ and $\eta > 0$, i.e., $I^e_0 > 0$ and $D^i_{0,f} = 0$. In this case, the exporting country does not experience a stockout, but the fundamental demander uses domestic commodity only. This is because collateral demand is so strong that $S^e_0 + h > S^i_0$.

Case 3. $\lambda > 0$ and $\eta = 0$, i.e., $I^e_0 = 0$ and $D^i_{0,f} > 0$. In this case, the exporting country experiences a stockout, but the fundamental demander uses both domestic and foreign commodity.

Case 4. $\lambda > 0$ and $\eta > 0$, i.e., $I^e_0 = 0$ and $D^i_{0,f} = 0$. In this case, the exporting country experiences a stockout, and the fundamental demander uses domestic commodity only.

The detailed solutions for the four cases are provided in Appendix B.1. Case 1 is arguably the most natural case and represents "normal market conditions."

## 4.2 Benchmark Equilibrium without Collateral Demand

In the benchmark case, we exogenously shut down the collateral demand for commodities, i.e., forcing $C_0^i = 0$. (The financial investor in the importing country can still trade futures contracts.) This case applies, for example, if capital control is relaxed substantially so that moving financial capital into China is more efficient than importing physical commodities for financing purposes.

In this benchmark case, since the exporting country is a net supplier in time 0 and time 1, its commodity must eventually be absorbed by fundamental demander in the importing country. Following similar (but simpler) calculation as before, we have the following proposition.

**Proposition 2.** *Suppose that collateral demanders of commodities do not participate in the market. In equilibrium, the spot prices ($S_0^e$, $S_1^e$, $S_0^i$, $S_1^i$) and the inventory $I_0^e$ in the exporting country are given by the solution to the following system of equations:*

$$G_0^e - I_0^e = \frac{k_0 - S_0^i}{2l} - a - bS_0^i, \tag{46}$$

$$I_0^e(1-\delta) + G_1^e = \frac{\gamma_s^e + \gamma_p^e}{\gamma_s^e \gamma_p^e} \frac{E\left[S_1^e - F^e\right]}{\left(\sigma_S^e\right)^2}, \tag{47}$$

$$I_0^e(1-\delta) + G_1^e = \frac{k_1 - S_1^i}{2l} - \left(a + bS_1^i\right), \tag{48}$$

$$S_1^i = S_1^e + h, \tag{49}$$

$$S_0^i = S_0^e + h - 2l\eta, \tag{50}$$

*where*

$$F^e = \frac{S_0^e(1+r^e) - \lambda}{1-\delta}. \tag{51}$$

*The explicit equilibrium solution is provided in Appendix B.2.*

## 4.3 Technical Conditions

For simplicity, we restrict attention to parameters that satisfy the following conditions. First, $\lambda = 0$ and $\eta = 0$ in the benchmark case without collateral commodity. Second, for the collateral channel to be nontrivial, the parameters are such that if demanders of collateral commodity participate in the market, they import a positive amount. Third, the parameters are such that the commodity producer in the importing country does not wish to carry inventory. These three parameter restrictions are summarized as Technical Condition 1 and 2, provided in Appendix B.3. These two technical conditions are maintained throughout the paper. Relaxing them would complicate the analysis but does not change the qualitative nature of the results.

# 5 The Effects of Demand for Collateral Commodity and Comparative Statics

In this section we compare the equilibrium of Proposition 1 to the equilibrium of Proposition 2. We interpret the difference as the impact of the collateral demand for commodities on commodity prices, convenience yield, inventory, futures risk premium, and real demand for commodities. We also study how the unsecured interest rate $R^i$ in the importing country affects these variables in the equilibrium of Proposition 1. All proofs are in Appendix C.

## 5.1 Prices

**Proposition 3** (Effect on Prices)**.** *The collateral demand for commodities:*

1. *Increases the spot prices at time 0,* $S_0^e$ *and* $S_0^i$*.*
2. *Reduces the spot prices at time 1,* $S_1^e$ *and* $S_1^i$*, for a fixed fundamental shock* $k_1$*.*

The intuition for Proposition 3 is simple. Since there is an extra collateral demand for commodities at time 0, it will increase the spot price at time 0. And because these extra collateral commodities are sold at time 1, they reduce the time-1 spot prices $S_1^i$ in the importing country. Figure 3 provides a numerical example of the time-0 spot prices.

## 5.2 Convenience Yield

The convenience yield of a commodity is the benefit of holding this commodity versus holding a futures or forward contract. In the prior literature it usually comes from the real option of consuming commodities anytime, especially if the commodity is scarce and cannot be bought quickly in the spot market. The convenience yield can be mathematically defined as the carry cost of the commodity less the spot-futures spread. In our model, the convenience yield in country $j \in \{e, i\}$ is obtained as

$$y^j = -\frac{F^j}{S_0^j} + \frac{1 + r^j}{1 - \delta}. \tag{52}$$

Figure 3: Spot prices as functions of $R^i$, with and without collateral demand

Model parameters: $r^e = 0$, $r^i = 0.05$, $R^e = 0.06$, $\delta = 0.01, h = 0.5, G_0^e = G_1^e = 11, k_0 = 45, u_k = 50, \sigma_k = 0.5, l = 1, a = -5, b = 1, \gamma_p^e = 1, \gamma_s^e = 1, \gamma_d^i = 2$ and $\gamma_c^i = 2$. For these parameters the minimum $R^i$ that satisfies Technical Conditions 1 and 2 is about 0.08.


From (11), one can see that the convenience yield $y^e$ in the exporting country is

$$y^e = \frac{\lambda}{S_0^e (1 - \delta)}. \tag{53}$$

In our model this convenience yield is zero unless a stockout happens ($I_0^e = 0$) in the exporting country, which corresponds to a positive $\lambda$. This is consistent with the theory of storage, in which the convenience yield arises because of the possibility of a stockout (see, for example, Deaton and Leraque (1992, 1996) and Routledge, Seppi and Spatt (2000)).

From (31), with collateral demand, the convenience yield in the importing country is

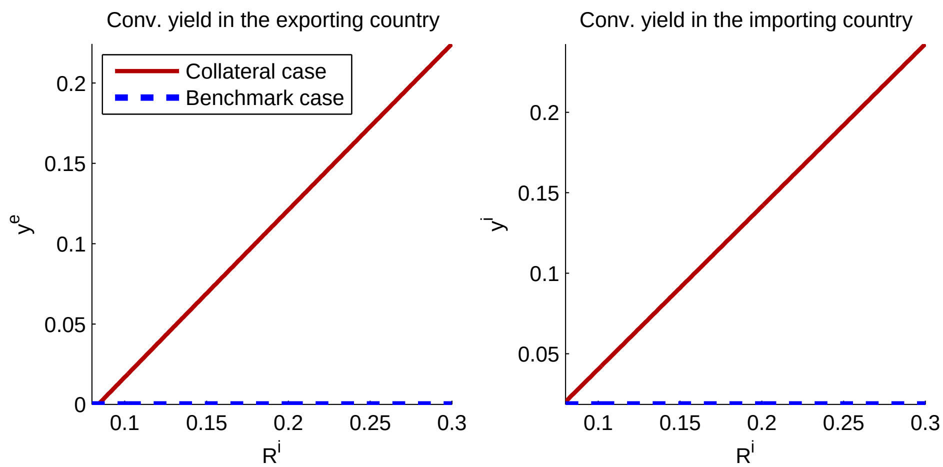
$$y^i = \frac{R^i - R^e}{1 - \delta} - \frac{2l (1 + R^e)}{(1 - \delta) S_0^i} \eta. \tag{54}$$

It is linearly related to the spread between the unsecured interest rates in the two countries, $R^i - R^e$, which is a key driver for the collateral demand. To distinguish it from the theory of storage, we call $y^i$ the "convenience yield of collateral."

By contrast, the convenience yield in the importing country without collateral demand is given by

$$\overline{y}^i = -\frac{q}{\overline{S}_0^i} + (1 - \delta) + \frac{1 + r^i}{1 - \delta}, \tag{55}$$

Figure 4: Convenience yields as functions of $R^i$, with and without collateral demand. Model parameters are those of Figure 3.




which does not depend on $R^e$ or $R^i$. We use the "bar" notation to denote variables in the benchmark equilibrium without collateral demand. The following proposition reveals that in equilibrium, the collateral demand for commodity increases the convenience yield relative to the benchmark case, i.e., $y^i > \overline{y}^i$.

**Proposition 4** (Effect on Convenience Yield)**.** *The collateral demand for commodities:*

1. *Increases the convenience yield in the importing country.*
2. *Increases the convenience yield in the exporting country if and only if* $\lambda > 0$ *(i.e. a stockout).*

Figure 4 provides a numerical example of convenience yields in the two countries as functions of $R^i$.

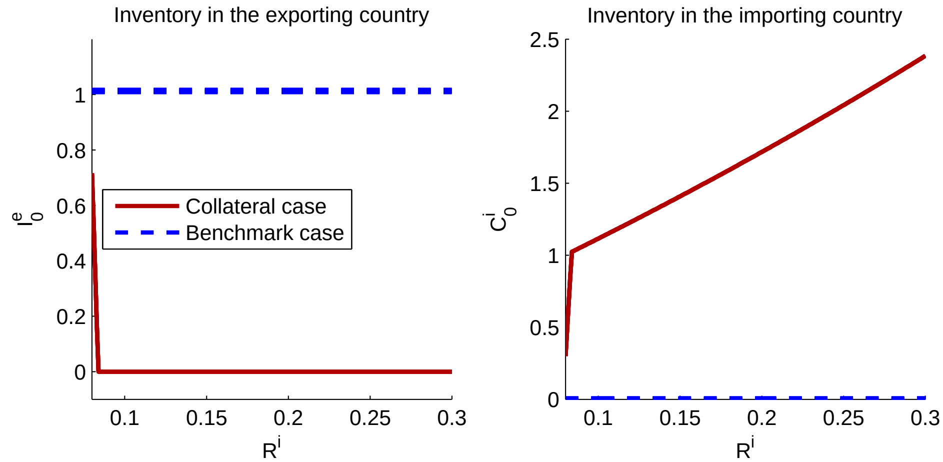
## 5.3 Inventories

**Proposition 5** (Effect on Inventories)**.** *The collateral demand for commodities:*

1. *Reduces the inventory* $I_0^e$ *in the exporting country.*
2. *Increases the inventory* $C_0^i$ *in the importing country.*
3. *Increases the total inventory* $I_0^e + C_0^i$ *in both countries.*

Since the additional collateral demand increases the spot prices, the producer in the exporting country holds less inventory. Obviously, inventory in the importing country, $C_0^i$, goes up because collateral commodity must be stored. Total global inventory also

Figure 5: Inventories as functions of $R^i$, with and without collateral demand. Model parameters are those of Figure 3.




goes up. Figure 5 shows a numerical example of inventories as functions of $R^i$. For $R^i$ above 0.084 the exporting country experiences a stockout, hence the kink in the convenience yields.

Combining Proposition 4 and Proposition 5, we obtain the following corollary:

**Corollary 1.** *The collateral demand for commodities makes the correlation between inventory and convenience yield positive in the importing country.*

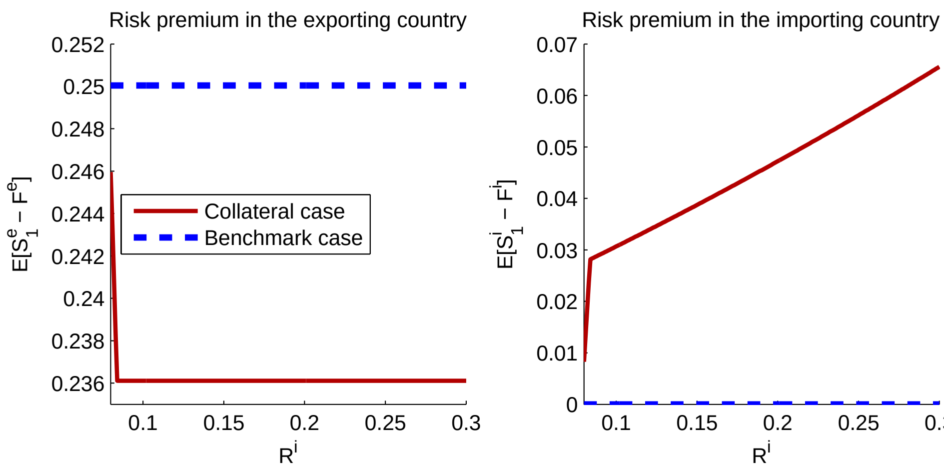
## 5.4 Commodity Futures Risk Premium

**Proposition 6** (Effect on Commodity Futures Risk Premium)**.** *The collateral demand for commodities:*

1. *Reduces the futures risk premium in the exporting country,* $E[S_1^e - F^e]$.
2. *Increases the futures risk premium in the importing country,* $E[S_1^i - F^i]$.

Equation (12) shows that the futures risk premium in the exporting country is proportional to $[I_0^e(1-\delta) + G_1^e]$, which can be considered as the total quantity the producers need to hedge. The theory of normal backwardation as in Keynes (1923), Hirshleifer (1990) and Bessembinder (1992) argues that hedgers need to offer risk premiums in order to solicit speculators to offset their trades; thus, the futures risk premium relates positively to the amount producers hedge. Our model is consistent with this idea. The extra collateral demands reduces the amount of inventory $I_0^e$,

Figure 6: Commodity futures risk premium as functions of $R^i$, with and without collateral demand. Model parameters are those of Figure 3.




which in turn reduces the futures risk premium in the exporting country. Similarly, the futures risk premium in the importing country is proportional to $(1 - \delta)\, C_0^i$.

Figure 6 plots the futures risk premium in two countries as functions of $R^i$. Collateral demand for commodity reduces the futures risk premium in the exporting country but increases that in the importing country. Comparing Figure 6 with Figure 5, we observe that the shapes of the futures premium resemble those of the inventories. Again, this is because futures risk premium in our model is linear in the amount of inventory that needs to be hedged.

## 5.5 Real Demand for Commodity

**Proposition 7** (Effect on Real Demand)**.** *For a fixed fundamental shock $k_1$, the collateral demand for commodities:*

1. *Reduces the real demand for commodities in the importing country at time 0.*
2. *Increases the real demand for commodities in the importing country at time 1.*
3. *Reduces the sum of time-0 and time-1 real demands for commodities in the importing country.*

As the collateral demand increases the spot price at time 0 in the importing country, it also decreases the real demand for the commodity. As the collateral commodities are sold at time 0, the spot price at time 1 decreases in the importing country and the real demand increases. But because a larger amount of commodities is stored between the two periods, a larger deadweight loss is incurred. The total real demand is reduced by the demand for collateral commodity.

This real effect of using commodity as collateral complements to that of Kiyotaki and Moore (1997). In their model, production assets such as land and machineries can also be pledged as collateral. They show that a small, temporary negative shock to firms' net worth can be amplified to large, persistent shock to the prices of assets and firms' investments and production. Our model is complementary in that the production asset, commodity, is a traded asset, and firms not involved in the real production can also import commodity to generate financial returns. In our model, if the production functions of the real sector is invariant to the interest rate, as we implicitly assume in Proposition 7, more financial demand for commodity crowds out the real demand by increasing commodity spot prices and by increasing the deadweight loss of commodity storage. If, however, production constraint can be relaxed by importing commodities as collateral, we may reasonably expect the collateral demand for commodity to increase total output at the cost of amplification and fragility, as in Kiyotaki and Moore (1997). The latter effect is not in our current analysis because we expect it to be similar to that modeled by Kiyotaki and Moore (1997). The welfare implications of using commodities as collateral is therefore ambiguous.

### 5.6 Comparative Statics with respect to Unsecured Rate $R^i$

By the same intuition as the effects of collateral commodity, we can derive the effect of raising the unsecured interest rates $R^i$ in the importing country in the equilibrium of Proposition 1.

**Proposition 8.** *Holding other parameters fixed, in Case 1 of the equilibrium of Proposition 1, as the unsecured interest rate $R^i$ increases in the importing country:*

1. *The spot prices in importing and exporting countries at time 0, $S_0^i$ and $S_0^e$, increase.*
2. *The collateral inventory $C_0^i$ in the importing country increases, the inventory $I_0^e$ in the exporting country decreases, and the total inventory increases.*
3. *The convenience yield in the importing country $y^i$ increase.*
4. *The futures risk premium in the exporting country $E\left[S_1^e - F^e\right]$ decreases, and the futures risk premium in the importing country $E\left[S_1^i - F^i\right]$ increases.*

Proposition 8 is written for Case 1 of Proposition 1, but the same qualitative results hold for other three cases. The only caveat is that if $R^i$ is sufficiently high, certain endogenous variables may become flat in $R^i$. For instance, if $\eta > 0$, $S_0^i$ is invariant to $R^i$ (see Appendix B.2, Case 2).

The result that commodity price can increase in the interest rate of the importing country complements existing theory and evidence on the relation between interest rate and (real) commodity prices. For example, Frankel (1986, 2008) show that high interest rates reduce the price of storable commodities by increasing the incentive for commodity extraction now rather than in the future, by decreasing firms' desire to carry inventories, and by encouraging speculators to shift out of commodity contracts and into Treasury bills. He finds a significant and negative coefficient of real commodity price on the real US interest rate, representing global monetary policy, as well as on the real interest rate differential between the non-US countries and the US, representing local variations in monetary policy. The foreign countries used in Frankel's analysis include Australia, Brazil, Canada, Chile, Mexico, New Zealand, Switzerland and UK. The first six countries are major exporting countries of commodities, whereas the last two are important commodity trading centers that hold large inventories. Frankel's results, as well as the explanation based on costs of commodity extraction and inventory, apply well in these countries.

Complementary to Frankel's work, our result focuses on the collateral channel, which applies to countries that *import* commodities to circumvents capital control. For these countries, most notably China, a higher unsecured interest rate can counterintuitively increase the demand for collateral and hence increase the global price of commodities.

# 6 Data

This section describes the data that we used to test the model predictions.

## 6.1 Proxy for the Collateral Demand for Commodities

Ideally, one would want to measure the quantity of commodities that are pledged to lenders as financing collateral. Unfortunately, such data are unavailable, except the approximate industry estimate (see the Introduction). Instead, we start from our theoretical framework and construct a proxy for the attractiveness of importing commodities as collateral.

As we have discussed, the attractiveness of importing commodities as collateral relies on two key frictions. First, unsecured interest rates in China must be sufficiently high relative to that in developed markets, reflecting collateral constraints and immature credit market in China. Second, because of capital control, it is difficult to take advantage of this funding gap by directly moving financial capital into China.

As proxies for unsecured interest rates in China and developed markets, we use CNY Shibor, the Shanghai Interbank Offered Rate, and USD Libor, the London Interbank Offered Rate.[13] The gap in unsecured rates is:

$$\pi_t = \text{Shibor}_t - \text{Libor}_t. \tag{56}$$

In the normal case of the model (where neither Lagrange multiplier is binding), the expected profit for importing one unit of commodity as collateral can be written as (see (24)):

$$S_0^i(R^i - R^e) + (1-\delta)E[S_1^i] - S_0^i(1 + r^i). \tag{57}$$

The first term of the above expression is proportional to the spread of the unsecured interest rates, $R^i - R^e$. The last two terms are the expected net cost of carrying one unit of inventory over one period, which is not related to the collateral channel.

A couple of remarks are in order. First, since Libor and Shibor are interbank rates, it is quite likely that they underestimate the *level* of unsecured interest rates at which the financial investors can borrow (in USD) and lend (in CNY). But the main objective of using the Shibor-Libor spread is to proxy the *time variation*, not the level, in the actual but unobserved spread in unsecured interest rates. To the extent that this measure is noisy, it would make it more difficult for us to find results in the data. Second, although Shibor is relatively recent (starting in 2006), it closely tracks the actual interbank lending rates calculated by the People's Bank of China at monthly frequency (see Figure 7). We use Shibor in the main analysis because it is available at a higher frequency than the actual lending rates.

Our sample period is from October 13, 2006 to November 14, 2014, with 423 weekly observations.

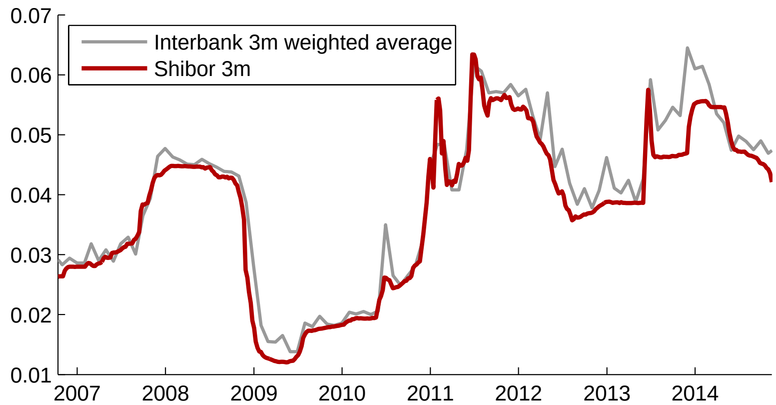
Figure 8(a) plots the time-series behaviors of Libor and Shibor. While Libor and Shibor are comparable before 2009, Shibor raises substantially above Libor after 2009.

To measure the tightness of capital control in China, we use the percentage deviation from the covered interest rate parity (CIP) in the USDCNY exchange rate:

$$f_t = \frac{\text{USDCNYSpot}_t \cdot e^{(\text{Shibor}_t - \text{Libor}_t)/4}}{\text{USDCNYForward}_t} - 1, \tag{58}$$

[13]Another measure would be the unsecured interest rates paid by nonbank firms, but long time series of such data could not be found. The Wenzhou Private Finance Index started only in late 2012.

Figure 7: Shibor (weekly) versus quantity-weighted average lending rate (monthly)



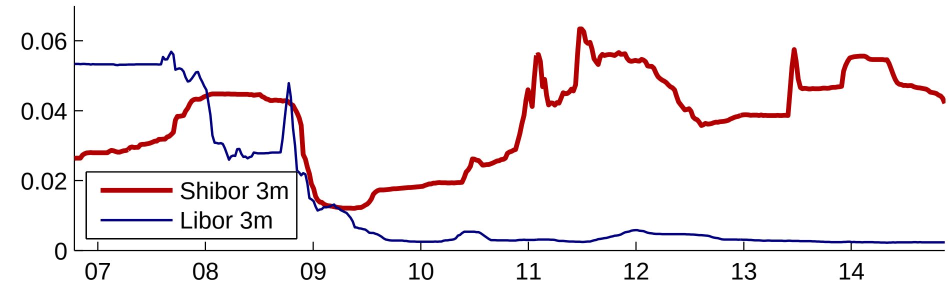

Data source of actual lending rates: People's Bank of China

where $\text{USDCNYSpot}_t$ is the official spot USDCNY exchange rate and $\text{USDCNYForward}_t$ is the 3-month non-deliverable forward (NDF) exchange rate of USDCNY, both downloaded from Datastream. An NDF is the same as a usual forward contract except that on the delivery date, the NDF is cash settled in USD, rather than by physically delivering CNY against USD. This is because the CNY is not freely convertible and physical delivery is difficult, if possible at all. Before the development of the offshore CNY market in mid-2010, the NDF market is the predominant means for foreign investors to take positions on the CNY. For more details of the USDCNY NDF, see Yu (2007) and ASIFMA (2014).

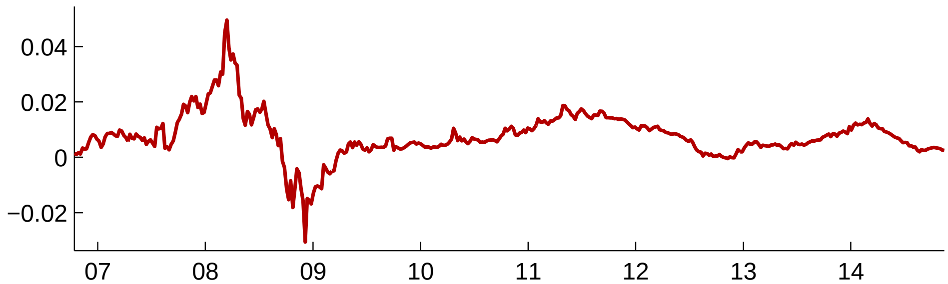
Figure 8(b) plots the time series of the the deviation from CIP. The deviation $f_t$ is positive most of the time, implying that the market expects the appreciation of CNY against USD. The sole exception is in late 2008, the depth of the crisis.[14] Because of capital control, this deviation from the CIP cannot be eliminated by the usual arbitrage trades, which involve buying CNY spot and selling CNY forward, both physically delivered. The higher is the deviation, the stronger is the incentive to gain access to CNY investments by circumventing capital control, such as by importing

[14] Violation of CIP also exists in other currency pairs. Pasquariello (2014) constructs a measure of CIP violations over a broader set of currencies from 1990 to 2009. In his sample the CIP violation is around 0.2% before the crisis, with a peak around 0.8% in 2009. By contrast, the CIP violations on USDCNY are high in early 2008, mid 2011, and early 2014, with larger magnitude on each occasion. Thus, China-specific capital control is likely the dominant friction in driving CIP violation on USDCNY (in addition to higher funding and transaction frictions in developed countries during the financial crisis).

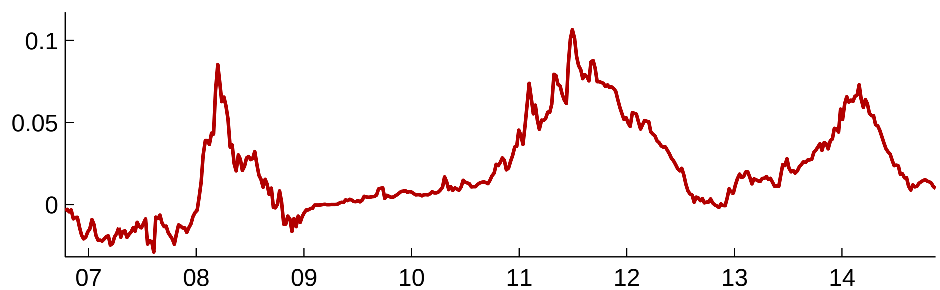
Figure 8: Collateral-demand-for-commodities proxy and its components




(a) Libor and Shibor




(b) Deviation from covered interest rate parity $f_t$



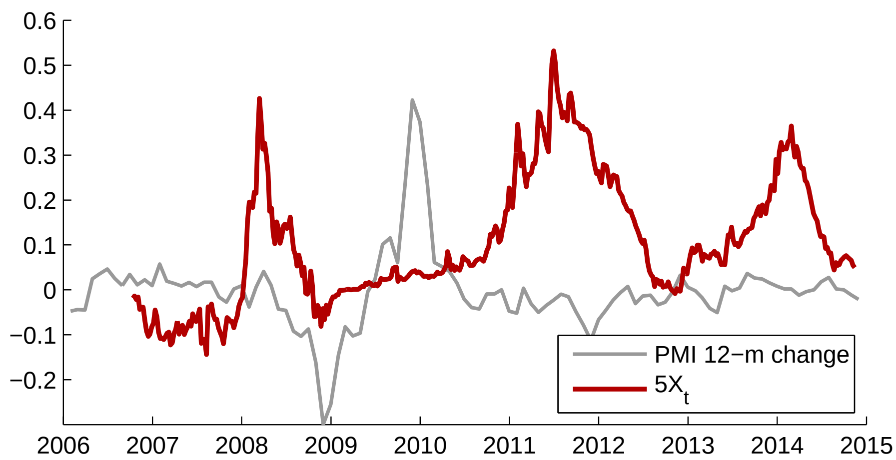

(c) Collateral-demand-for-commodities proxy $X_t$

commodities.[15] The deviation $f_t$ is thus a proxy for the tightness of capital control.[16]

[15] There are other ways to circumvent capital control. For example, Desai, Foley, and Hines (2006) report that US multinational firms circumvent capital control by reducing reported foreign profitability and increasing dividends repatriation. In recent years it also has been widely suspected that certain companies in China "over-invoice" exports as way to bring capital into China. See, for example, "China to crack down on faked export deals" by Simon Rabinovitch, Financial Times, May 6, 2013.

[16] One could also view $f_t$ as a proxy for the market expectation of CNY appreciation. The higher is $f_t$, the less currency risk is in the final leg of the trading, i.e., buying USD against CNY to repay the USD letter of credit. Note, however, that the financial investors who owe USD can always hedge currency risk by buying USD forward against CNY (e.g., with a bank). Therefore, it is not clear how much "currency speculation" is conducted by the

Figure 9: $X_t$ (weekly) versus China PMI 12-month change (monthly). $X_t$ is scaled by 5 to match the magnitude of PMI change.




Our final proxy for the collateral demand for commodities is the product of the Shibor-Libor spread, $\pi_t$, and the deviation from covered interest rate parity, $f_t$, multiplied by 100:

$$X_t = 100\pi_t f_t. \tag{59}$$

This measure is shown in Figure 8(c). Since 2008 this measure is predominantly positive and strongly time-varying. The only periods when $X_t$ is negative are in early part of the sample, before 2008 and in late 2008, and the magnitude is small. Importantly, $X_t$ and China's macroeconomic fundamentals are essentially uncorrelated. For instance, the monthly sample of $X_t$ and China PMI 12-month change has a correlation of $-0.09$ (see Figure 9).

## 6.2 Commodity Prices and Inventories

Commodities that we use to test the theory are selected by two criteria. First, the commodities should have active futures or forward markets in China and in developed countries (e.g. US, UK, Japan). Second, data for commodity prices and inventories should go back to at least the start of 2009, when Shibor started to raise substantially above Libor.

Applying these two criteria, we end up with eight commodities: copper, zinc, alu-

financial investors by importing commodities.

minum, gold, soybean, corn, fuel oil, and natural rubber. We call the first four commodities the metal group, and the last four commodities the nonmetal group. We would expect the metals to be more suitable for collateral purposes as they are easier to store and have a higher value-to-bulk ratio than nonmetal commodities. Thus, our model implications should be more evident in the metal group than in the nonmetal group.

For each commodity, we use the leading exchange in China and the leading exchange in developed markets as price data source. With few exceptions, we take the prices of the first and third futures contracts in both the Chinese market and developed markets.[17,18] Also with few exceptions, all price and inventory data are weekly observations from October 13, 2006 to November 14, 2014.

Following the standard approach in the literature (see, for example, Gorton, Hayashi, and Rouwenhorst (2012)), we proxy commodities inventories by those in exchange warehouses whenever available. For our purposes of studying time variations, the inventory in exchange warehouses is a reasonable proxy for the market-wide inventory as long as they are sufficiently correlated with each other. Inventory data for copper, zinc, aluminum, gold, fuel oil, and natural rubber are obtained from various exchanges this way. Inventories of two agricultural commodities, soybean and corn, are obtained from U.S. Department of Agriculture.

Table 1 summarizes the data sources for commodity prices and inventories.

Besides $X_t$, other variables used in the empirical analysis are defined as follows.

- $\gamma_t$ denotes the local interest rate (Shibor or Libor).
- Because spot prices are often unavailable (except cash prices for copper, zinc, and aluminum on the LME), we follow Pindyck (2001) and infer the spot prices $S_t$ from traded futures prices by extrapolation.
- $y_t$ denotes the convenience yield in the Chinese market or developed markets, calculated as

$$y_t = \frac{\ln(F(t,T_1)) - \ln(F(t,T_2))}{T_2 - T_1} + \gamma_t, \tag{60}$$

  where $F(t,T_1)$ and $F(t,T_2)$ are futures prices at week $t$ with maturity $T_1$ and $T_2$, respectively.

[17] Exceptions include the following. The price data for copper, zinc, and aluminum are obtained from LME as cash price and 3-month forward price, not futures prices. For some commodities we use the second contract. Since fuel oil futures are not available in the US, we use CME heating oil futures to proxy the fuel oil futures. (Fuel oil is one type of heating oil.)

[18] Commodities traded in China are in CNY. Commodities traded in developed markets are in USD. (Rubber prices are originally in JPY, and we convert them to USD.) We do not convert CNY to USD as CNY is not fully convertible.

Table 1: Data sources of commodities prices and inventories

*Acronyms.* SHFE: Shanghai Futures Exchanges. LME: London Metal Exchange. DCE: Dalian Commodity Exchanges. CME: CME Group. TOCOM: Tokyo Commodity Exchange. USDA: United States Department of Agriculture.

| | Price data source | | Inventory data source | |
|---|---|---|---|---|
| Commodity | China | Developed Market | China | Developed Market |
| Copper | SHFE, first and third futures | LME, cash and 3-month forward | SHFE | LME |
| Zinc | SHFE, first and third futures | LME, cash and 3-month forward | SHFE | LME |
| Aluminum | SHFE, first and third futures | LME, cash and 3-month forward | SHFE | LME |
| Gold | SHFE, first and third futures | CME, first and third futures | SHFE | CME |
| Soybean | DCE, first and third futures | CME, first and second futures | USDA | USDA |
| Corn | DCE, first and third futures | CME, first and second futures | USDA | USDA |
| Fuel oil | SHFE, first and third futures | CME, first and third futures | SHFE | CME |
| Natural rubber | SHFE, first and third futures | TOCOM, first and second futures | SHFE | TOCOM |

- We denote by

$$\theta_t = \ln(F(t,T)) - \ln(F(t-1,T)) \tag{61}$$

  the excess return (risk premium) of holding the far-maturity futures contract for one week. For LME metals (copper, zinc, aluminum), this return is calculated from the 3-month forward with a small adjustment.[19]

- We denote by $I_t$ the inventory in China or developed markets. Because inventories tend to have a time trend, we detrend the inventory level by the average inventory over the previous year:

$$\hat{I}_t = I_t - \frac{1}{52}\sum_{j=1}^{52} I_{t-j}. \tag{62}$$

  The detrended inventory $\hat{I}_t$ will be our main measure of inventory. Detrending inventory is a common approach in the literature (see, for example, Gorton, Hayashi, and Rouwenhorst (2012)).

Table 2 reports the summary statistics of the main variables. Most variables are multiplied by 100 to reduce the number of digits.

[19]Specifically, let $F_{t,t+13}$ be the 3-month forward price of the commodity observed in week $t$. The hypothetical forward price with 14 weeks to maturity in week $t$ is approximated by $F_{t,t+14} = F_{t,t+13}e^{(\gamma_t - y_t)/52}$. In week $t+1$, the 3-month forward contract matures in week $t+14$. So the return is $\ln(F_{t+1,t+14}) - \ln(F_{t,t+14}) = \ln(F_{t+1,t+14}) - \ln(F_{t,t+13}) - \frac{1}{52}(\gamma_t - y_t)$.

Table 2: Summary statistics

$\pi_t$ is the Shibor-Libor spread. $f_t$ is the deviation from the CIP. $X_t \equiv 100\pi_t f_t$. $\gamma_t$ is the local interest rate. $S_t$ is the (extrapolated) spot price of commodities. $y_t$ is the local convenience yield. $\theta_t$ is the futures risk premium.

| | | mean | std. dev. | median | | | |
|---|---|---|---|---|---|---|---|
| $X_t$ | | 0.021 | 0.028 | 0.014 | | | |
| $\pi_t$ | | 0.023 | 0.024 | 0.025 | | | |
| $f_t$ $(\times 10^2)$ | | 0.766 | 0.824 | 0.661 | | | |
| | | | China | | | Developed Market | |
| | | mean | std. dev. | median | mean | std. dev. | median |
| $\gamma_t$ $(\times 10^2)$ | | 3.74 | 1.31 | 3.94 | 1.44 | 1.84 | 0.39 |
| $\Delta \ln(S_t)$ $(\times 10^2)$ | Copper | -0.09 | 3.53 | -0.05 | -0.02 | 4.23 | -0.03 |
| | Zinc | -0.17 | 3.63 | 0.10 | -0.12 | 4.73 | -0.20 |
| | Aluminum | -0.10 | 2.15 | -0.11 | -0.06 | 3.41 | -0.20 |
| | Gold | 0.05 | 2.87 | 0.03 | 0.06 | 2.45 | 0.33 |
| | Soybean | 0.07 | 3.22 | -0.23 | 0.13 | 4.26 | 0.48 |
| | Corn | 0.15 | 2.16 | 0.06 | 0.05 | 5.00 | 0.35 |
| | Fuel Oil | 0.01 | 5.63 | 0.10 | 0.08 | 4.21 | 0.12 |
| | Rubber | -0.12 | 4.12 | 0.24 | -0.02 | 5.98 | 0.02 |
| $y_t$ $(\times 10^2)$ | Copper | 8.94 | 12.55 | 6.74 | 1.79 | 3.75 | 0.20 |
| | Zinc | -1.45 | 10.22 | -1.78 | -2.56 | 3.93 | -3.21 |
| | Aluminum | 0.73 | 12.85 | -0.42 | -4.44 | 4.63 | -5.13 |
| | Gold | 1.13 | 11.95 | 1.34 | -0.38 | 1.03 | -0.32 |
| | Soybean | 11.68 | 16.71 | 13.52 | 8.59 | 25.26 | -1.34 |
| | Corn | -3.65 | 12.48 | -4.77 | -3.26 | 20.15 | -9.25 |
| | Fuel Oil | -12.00 | 30.65 | -12.80 | -3.99 | 9.81 | -3.09 |
| | Rubber | 2.02 | 21.41 | -3.30 | 0.67 | 33.38 | -4.68 |
| $\theta_t$ $(\times 10^2)$ | Copper | -0.09 | 3.91 | -0.03 | -0.02 | 4.18 | -0.01 |
| | Zinc | -0.17 | 3.69 | 0.16 | -0.20 | 4.61 | -0.29 |
| | Aluminum | -0.09 | 2.10 | 0.00 | -0.18 | 3.30 | -0.24 |
| | Gold | 0.03 | 2.27 | 0.07 | 0.07 | 2.39 | 0.29 |
| | Soybean | 0.06 | 3.06 | 0.00 | 0.13 | 3.84 | 0.40 |
| | Corn | 0.13 | 1.43 | 0.00 | 0.05 | 4.79 | 0.31 |
| | Fuel Oil | 0.02 | 4.16 | 0.00 | 0.06 | 3.90 | 0.31 |
| | Rubber | -0.09 | 4.28 | 0.01 | -0.02 | 5.09 | -0.05 |

# 7 Empirical Evidence

In this section, we test the predictions of our model. Motivated by the predictions of our theory (Section 5), we test how the commodity-as-collateral proxy $X_t$ affects: (i) commodity prices, and (ii) commodity futures risk premium, and (iii) the relation between inventory and convenience yield.

## 7.1 Commodity Prices

Proposition 3 and Proposition 8 predict that the collateral demand for commodities increases their spot prices. To test this prediction, for each commodity, we regress the log price change on contemporaneous changes in local convenience yield, local interest rate, and the collateral-demand-for-commodities proxy:

$$\Delta \ln(S_t) = a + b\Delta y_t + c\Delta\gamma_t + d\Delta X_t + \epsilon_t. \tag{63}$$

The local convenience yield and local interest rates are control variables for the benefit and opportunity cost of holding commodities. For example, Pindyck (1993) argues that because the convenience yield is considered a benefit of holding commodities, spot prices should have a cointegration relation with convenience yield. Frankel (2008) shows that a higher interest rate is associated with lower commodity prices.

We also run separate panel regressions on the the metal group and nonmetal group:

$$\Delta \ln(S_{i,t}) = a_i + b\Delta y_{i,t} + c\Delta\gamma_{i,t} + d\Delta X_t + \epsilon_{i,t}. \tag{64}$$

Our theory predicts that the coefficient $d$ on $\Delta X_t$ should be positive in both China and developed markets.

Table 3 reports the results. As predicted by our theory, the panel regression for the metal group shows a significantly positive $d$, suggesting that a higher demand to import commodities as collateral to China is associated with a higher commodity prices globally. Commodity-by-commodity regressions reveal a significantly positive $d$ for copper, zinc, and aluminum on the LME and gold in China. All other individual regressions are statistically insignificant but show the expected sign.

By contrast, the nonmetal group of commodities generally have an insignificant coefficient $d$ on $\Delta X_t$, although they all have the expected sign. This insignificance is intuitive. Because the nonmetal group of commodities are bulky and relatively expensive to store and ship, they are not as desirable collateral as metals. (In our model, agricultural commodities and oil can be viewed as having a large shipping cost $h$ and a large storage cost $\delta$.)

The price effect of commodity collateral is economically large. The minimum and maximum of $X_t$ in our sample are $-0.029$ and $0.106$, with a range of about $0.135$. Counting only the statistically significant entries in the metal group, we see that an increase of $X_t$ of size 0.135 corresponds to 15.0% increase in copper price, 13.6% increase in zinc price, and 11.9% increase in aluminum price on the LME. The corresponding

Table 3: Commodity spot prices

Panel (a) reports the panel regressions (64) for the metal group and nonmetal group, where we have suppressed the commodities fixed effects $\{a_i\}$. Panel (b) reports the regressions (63) for individual commodities. Standard errors are calculated using the Newey-West method with 52 lags. Statistical significance at the 10%, 5% and 1% levels is denoted by ***, ** and *, respectively.

| | **Metal Group** | | | | **Nonmetal Group** | | | |
|---|---|---|---|---|---|---|---|---|
| **(a) Panel Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| $\Delta y_{it}$ | 0.084*** | 3.858 | 0.909*** | 7.900 | 0.154*** | 8.215 | 0.133*** | 6.806 |
| $\Delta \gamma_{it}$ | -0.707 | -1.330 | -0.426 | -0.584 | -0.594 | -0.953 | -4.587*** | -3.276 |
| $\Delta X_t$ | 0.656*** | 2.624 | 0.903*** | 3.922 | 0.247 | 1.266 | 0.405 | 1.469 |
| $R^2$ | 0.051 | | 0.103 | | 0.318 | | 0.195 | |
| $N$ | 1536 | | 1536 | | 1688 | | 1688 | |
| **(b) Individual Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| | **Copper** | | | | **Soybean** | | | |
| const | -0.001 | -0.516 | 0.000 | -0.156 | 0.001 | 0.441 | 0.001 | 0.436 |
| $\Delta y_{it}$ | -0.069 | -1.112 | 0.894*** | 6.032 | 0.192*** | 6.845 | 0.155*** | 5.559 |
| $\Delta \gamma_{it}$ | 0.652 | 0.630 | -0.859 | -0.533 | -0.555 | -0.691 | -3.308* | -1.850 |
| $\Delta X_t$ | 0.772 | 1.417 | 1.114** | 2.306 | 0.436 | 1.236 | 0.512 | 1.008 |
| $R^2$ | 0.029 | | 0.057 | | 0.340 | | 0.230 | |
| $N$ | 422 | | 422 | | 422 | | 422 | |
| | **Zinc** | | | | **Corn** | | | |
| const | -0.002 | -0.761 | -0.001 | -0.556 | 0.001* | 1.826 | 0.000 | -0.018 |
| $\Delta y_{it}$ | 0.039 | 0.952 | 1.173*** | 8.947 | -1.372* | -1.874 | -4.402*** | -3.743 |
| $\Delta \gamma_{it}$ | -2.123** | -2.477 | -0.359 | -0.294 | 0.315 | 9.047 | 0.180 | 8.873 |
| $\Delta X_t$ | 0.987 | 1.613 | 1.009* | 1.944 | 0.001 | 0.003 | 0.548 | 0.807 |
| $R^2$ | 0.019 | | 0.140 | | 0.469 | | 0.138 | |
| $N$ | 395 | | 395 | | 422 | | 422 | |
| | **Aluminum** | | | | **Fuel Oil** | | | |
| const | -0.001 | -0.902 | -0.001 | -0.388 | 0.000 | 0.130 | 0.000 | 0.181 |
| $\Delta y_{it}$ | 0.123*** | 2.886 | 1.002*** | 4.979 | 0.152*** | 6.306 | 0.487*** | 11.848 |
| $\Delta \gamma_{it}$ | 0.412 | 0.591 | 0.046 | 0.055 | -1.925** | -2.178 | -1.277 | -1.182 |
| $\Delta X_t$ | 0.183 | 0.845 | 0.880*** | 2.506 | 0.591 | 1.430 | 0.444 | 1.200 |
| $R^2$ | 0.092 | | 0.167 | | 0.470 | | 0.177 | |
| $N$ | 422 | | 422 | | 422 | | 422 | |
| | **Gold** | | | | **Rubber** | | | |
| const | 0.001 | 0.353 | 0.000 | 0.278 | -0.001 | -0.496 | -0.001 | -0.410 |
| $\Delta y_{it}$ | 0.143*** | 20.638 | 0.397*** | 14.376 | 0.094** | 2.046 | 0.116*** | 5.532 |
| $\Delta \gamma_{it}$ | -2.140*** | -3.761 | -9.096** | -2.082 | 1.246 | 0.882 | -9.118*** | -4.800 |
| $\Delta X_t$ | 0.715*** | 2.644 | 0.332 | 1.062 | 0.079 | 0.164 | 0.081 | 0.151 |
| $R^2$ | 0.437 | | 0.055 | | 0.049 | | 0.296 | |
| $N$ | 297 | | 297 | | 422 | | 422 | |

effect on gold price in China is 9.6%. These estimates reveal that China-specified frictions, reflected by the collateral demand for commodities, have important quantitative effects on global commodity prices.

## 7.2 Commodity Futures Risk Premium

Proposition 6 and Proposition 8 predict that an increase in the collateral demand for commodities tends to increase the futures risk premium in the importing country and reduce that in the exporting country. To test this prediction, we run the following regression, commodity by commodity:

$$\theta_t = a + by_{t-1} + c\gamma_{t-1} + dX_{t-1} + \epsilon_t. \tag{65}$$

We control for the convenience yield $y_{t-1}$ and lagged local interest rate $\gamma_{t-1}$. Gorton, Hayashi and Rouwenhorst (2012) show that convenience yield has a positive relation with commodity risk premium. Frankel (2008) argues that high interest rates tend to reduce inventory, which, in turn, can affect convenience yield through the hedging channel.

As before, we also run the panel-data version for the metal group and nonmetal group separately:

$$\theta_{i,t} = a_i + by_{i,t-1} + c\gamma_{i,t-1} + dX_{t-1} + \epsilon_{i,t}. \tag{66}$$

Our model predicts that the coefficient $d$ on the collateral-demand-for-commodities proxy $X_t$ should be positive in the Chinese market but negative in developed markets.

Table 4 reports the results. For the metal group the coefficient $d$ on $X_t$ is significantly positive for China and significantly negative for developed markets. Zinc shows the highest significance in both China and the LME, followed by gold (significant only in China). The coefficient $d$ for copper and aluminum has the predicted sign but is statistically insignificant. We also observe that the economic magnitude of the coefficient $d$ is about twice as large in China as in developed markets. For the nonmetal group neither the panel regression nor the individual commodity regressions show any statistical significance on $d$, with the sole exception of rubber in developed markets. Overall, these results are in line with the previous test and support our theory, albeit with somewhat weaker statistical significance.

Table 4: Commodity futures risk premium

Panel (a) reports the panel regressions (65) for the metal group and nonmetal group, where we have suppressed the commodities fixed effects $\{a_i\}$. Panel (b) reports the regressions (66) for individual commodities. Standard errors are calculated using the Newey-West method with 52 lags. Statistical significance at the 10%, 5% and 1% levels is denoted by ***, ** and *, respectively.

| | **Metal Group** | | | | **Nonmetal Group** | | | |
|---|---|---|---|---|---|---|---|---|
| **(a) Panel Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| $y_{i,t-1}$ | 0.009 | 1.018 | 0.001 | 0.018 | 0.018** | 2.004 | -0.015*** | -4.183 |
| $\gamma_{i,t-1}$ | -0.452*** | -4.030 | -0.253** | -2.382 | -0.354*** | -2.793 | -0.020 | -0.250 |
| $X_{t-1}$ | 0.153*** | 3.032 | -0.082** | -2.414 | 0.044 | 0.741 | -0.048 | -1.146 |
| $R^2$ | 0.019 | | 0.010 | | 0.023 | | 0.007 | |
| $N$ | 1536 | | 1536 | | 1688 | | 1688 | |
| **(b) Individual Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| | **Copper** | | | | **Soybean** | | | |
| const | 0.020** | 2.362 | 0.005 | 1.340 | 0.005 | 1.213 | 0.005** | 1.657 |
| $y_{i,t-1}$ | -0.004 | -0.168 | -0.082 | -1.191 | 0.021* | 1.881 | -0.022*** | -4.607 |
| $\gamma_{i,t-1}$ | -0.644** | -2.381 | -0.106 | -0.715 | -0.148 | -0.895 | -0.007 | -0.050 |
| $X_{t-1}$ | 0.175 | 1.636 | -0.090 | -1.148 | -0.048 | -0.572 | -0.079 | -1.306 |
| $R^2$ | 0.025 | | 0.011 | | 0.016 | | 0.023 | |
| $N$ | 422 | | 422 | | 422 | | 422 | |
| | **Zinc** | | | | **Corn** | | | |
| const | 0.017*** | 3.840 | 0.005 | 1.209 | 0.005*** | 3.121 | -0.001 | -0.207 |
| $y_{i,t-1}$ | 0.039*** | 2.700 | -0.037 | -0.644 | -0.007* | -1.773 | -0.010 | -0.980 |
| $\gamma_{i,t-1}$ | -0.609*** | -3.224 | -0.419* | -1.726 | -0.124** | -1.989 | 0.050 | 0.389 |
| $X_{t-1}$ | 0.220** | 2.215 | -0.130** | -2.397 | 0.030 | 0.901 | 0.009 | 0.161 |
| $R^2$ | 0.024 | | 0.023 | | 0.012 | | 0.003 | |
| $N$ | 395 | | 395 | | 422 | | 422 | |
| | **Aluminum** | | | | **Fuel Oil** | | | |
| const | 0.008*** | 2.712 | 0.007** | 2.189 | 0.021** | 2.333 | -0.001 | -0.320 |
| $y_{i,t-1}$ | 0.010 | 1.566 | 0.078** | 1.989 | 0.035*** | 3.455 | -0.002 | -0.094 |
| $\gamma_{i,t-1}$ | -0.284** | -2.344 | -0.255* | -1.860 | -0.528* | -1.782 | 0.025 | 0.164 |
| $X_{t-1}$ | 0.097 | 1.542 | -0.070 | -1.205 | 0.134 | 1.117 | 0.049 | 0.854 |
| $R^2$ | 0.020 | | 0.012 | | 0.078 | | 0.001 | |
| $N$ | 422 | | 422 | | 422 | | 422 | |
| | **Gold** | | | | **Rubber** | | | |
| const | 0.009*** | 4.358 | 0.000 | -0.094 | 0.021*** | 3.671 | 0.007 | 1.201 |
| $y_{i,t-1}$ | 0.003 | 0.431 | -0.166*** | -2.708 | -0.011 | -0.979 | -0.016*** | -3.685 |
| $\gamma_{i,t-1}$ | -0.383*** | -4.205 | -0.070 | -0.142 | -0.647*** | -2.655 | -0.201 | -1.114 |
| $X_{t-1}$ | 0.196*** | 3.140 | 0.027 | 0.536 | 0.121 | 0.897 | -0.211** | -2.301 |
| $R^2$ | 0.024 | | 0.005 | | 0.027 | | 0.019 | |
| $N$ | 297 | | 297 | | 422 | | 422 | |

### 7.3 Relation between Inventory and Convenience Yield

A negative relation between inventory and convenience yield is the key element in the theory of storage. In this theory, a low inventory corresponds to a high convenience of holding commodities because it increases the real option value of consuming commodity anytime. In our model of commodity as collateral, however, the relation is the reverse. As shown in Proposition 4, Proposition 5, and Corollary 1, an increasing collateral demand tends to simultaneously increase inventories and convenience yield in the importing country. Thus, complementary to the theory of storage, the collateral demands for commodity should make the inventory-convenience yield relation less negative in China.

To test the inventory-convenience yield relation in the presence of collateral use of commodities, we run the following regression for both China and developed markets, commodity by commodity:

$$y_t = a + b\hat{I}_t + c\hat{I}_t X_t + \varepsilon_t. \tag{67}$$

In addition, we run separate panel regressions for the metal group and nonmetal group. Because commodity inventories have different units and scales, to make sure that the coefficients are interpretable we normalize each detrended inventory by its time-series standard deviation:

$$y_{i,t} = a_i + b\frac{\hat{I}_{i,t}}{\sqrt{\mathrm{Var}(\hat{I}_{i,t})}} + c\frac{\hat{I}_{i,t}}{\sqrt{\mathrm{Var}(\hat{I}_{i,t})}} X_t + \varepsilon_{i,t}. \tag{68}$$

In both regressions (67) and (68), the coefficient $b$ captures the effect predicted by the theory of storage, and the coefficient $c$ captures the incremental effect predicted by our model of commodity as collateral. Our theory predicts that $c$ is positive in China, that is, the higher is benefit of importing commodities as collateral, the more positive (or the less negative) is the inventory-convenience yield relation. The theory does not make a prediction about $c$ in developed markets.

Table 5 reports the results of regressions (67) and (68). As predicted by the theory, the panel regression on the metal group in China shows a significantly positive coefficient $c$ on $\hat{I}_{i,t} X_t$. It reveals that the collateral use of commodities has a significant impact on the convenience yield-inventory relation. The same result is observed for all four commodities in the metal group: copper, zinc, aluminum, and gold. By contrast, the coefficient $c$ for the nonmetal group is generally insignificant, in both the panel

Table 5: Relation between convenience yield and inventory

Panel (a) reports the panel regressions (68) for the metal group and the nonmetal group, where we have suppressed the commodities fixed effects $\{a_i\}$. Panel (b) reports the regressions (67) for each individual commodity. Standard errors are calculated using the Newey-West method with 52 lags. Statistical significance at the 10%, 5% and 1% levels is denoted by ***, ** and *, respectively.

| | **Metal Group** | | | | **Nonmetal Group** | | | |
|---|---|---|---|---|---|---|---|---|
| **(a) Panel Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| $\hat{I}_{i,t}$ | -0.078*** | -5.970 | -0.012*** | -3.986 | -0.029* | -1.864 | -0.027 | -1.618 |
| $\hat{I}_{i,t} \cdot X_t$ | 0.804** | 2.505 | 0.116 | 1.296 | -0.211 | -0.688 | -0.115 | -0.334 |
| $R^2$ | 0.330 | | 0.411 | | 0.169 | | 0.058 | |
| $N$ | 1488 | | 1488 | | 1640 | | 1640 | |
| **(b) Individual Regressions** | China | | Developed Market | | China | | Developed Market | |
| | coef | t-stat | coef | t-stat | coef | t-stat | coef | t-stat |
| | **Copper** | | | | **Soybean** | | | |
| const | 0.094*** | 4.531 | 0.020* | 1.687 | 0.117*** | 3.874 | 0.085** | 2.121 |
| $\hat{I}_{i,t}$ | -4.951*** | -4.306 | -0.122** | -2.345 | -0.004 | -0.285 | -0.005 | -0.401 |
| $\hat{I}_{i,t} \cdot X_t$ | 65.614** | 2.383 | 1.731 | 0.978 | 0.264 | 0.922 | 0.189 | 0.919 |
| $R^2$ | 0.293 | | 0.091 | | 0.005 | | 0.004 | |
| $N$ | 423 | | 423 | | 423 | | 423 | |
| | **Zinc** | | | | **Corn** | | | |
| const | -0.025 | -1.620 | -0.031*** | -4.837 | -0.038 | -1.254 | -0.031 | -0.762 |
| $\hat{I}_{i,t}$ | -1.175*** | -8.318 | -0.114** | -2.006 | 0.004 | 0.562 | 0.000 | 0.092 |
| $\hat{I}_{i,t} \cdot X_t$ | 9.321*** | 3.283 | 0.806 | 0.800 | -0.191 | -1.289 | -0.060** | -1.986 |
| $R^2$ | 0.334 | | 0.155 | | 0.040 | | 0.012 | |
| $N$ | 344 | | 344 | | 423 | | 423 | |
| | **Aluminum** | | | | **Fuel Oil** | | | |
| const | 0.024 | 1.035 | -0.037*** | -2.836 | -0.121*** | -3.388 | -0.039** | -2.497 |
| $\hat{I}_{i,t}$ | -1.151*** | -3.890 | -0.024*** | -2.942 | -0.434*** | -3.361 | -5.249*** | -3.089 |
| $\hat{I}_{i,t} \cdot X_t$ | 11.401* | 1.778 | -0.372 | -0.493 | 0.069 | 0.021 | 33.702 | 0.792 |
| $R^2$ | 0.379 | | 0.092 | | 0.027 | | 0.279 | |
| $N$ | 423 | | 423 | | 423 | | 423 | |
| | **Gold** | | | | **Rubber** | | | |
| const | 0.006 | 0.858 | -0.004*** | -6.079 | 0.056* | 1.650 | 0.018 | 0.295 |
| $\hat{I}_{i,t}$ | -0.153*** | -4.024 | 0.001 | 1.215 | -3.856*** | -2.991 | -0.018 | -1.226 |
| $\hat{I}_{i,t} \cdot X_t$ | 6.094*** | 3.973 | -0.077** | -2.330 | 7.239 | 0.201 | 0.093 | 0.324 |
| $R^2$ | 0.095 | | 0.012 | | 0.201 | | 0.025 | |
| $N$ | 298 | | 298 | | 371 | | 371 | |

regression and individual commodity regressions. Overall, these results are consistent with the previous two tests and support our theory.

# 8 Conclusion

In this paper we propose and test a theory of using commodities as collateral for financing. In the presence of capital control and collateral constraint, financial investors import commodities and pledge them as collateral to capture a credit risk premium. A simple model shows that all else equal, the collateral demand for commodities increases the concurrent commodity spot prices, futures risk premium, inventory, and convenience yield all together in the importing country. Futures risk premium and inventory in the exporting country are reduced.

We test the model predictions in China and developed markets, using price and inventory data of four metals and four nonmetal commodities. Our empirical proxy for the collateral demand for commodities is the product of the Shibor-Libor spread, which is a proxy for the unsecured interest rates spread, and the deviation from the covered interest rate parity in the USD-CNY exchange rate, which is a proxy for the tightness of capital control by China.

Empirical tests strongly support our theory. A higher collateral demand for commodities is associated with (i) higher commodity prices globally, (ii) a higher futures risk premium in China and a lower futures risk premium in developed markets, and (iii) a less negative inventory-convenience yield relation in China. The economic magnitude is also large. For example, the estimates suggest that the collateral demand for commodities can explain up to 11.9%–15.0% price increase of major industrial metals since 2007.

Our contribution to the commodity literature can be summarized along the three important dimensions highlighted by Cheng and Xiong (2014): storage, risk sharing, and information discovery. On storage, we show that the relation between inventory and convenience yield, which is negative under the classic theory of storage, becomes significantly less negative if inventories are also held for collateral purposes. On risk sharing, we find evidence of inter-market spillover: commodity futures risk premium is strongly affected by interest rate spread across countries. On information discovery, we show that higher commodity prices do not necessarily imply strong fundamental demand; rather, they could reflect collateral demand caused by capital control and financing frictions.

More broadly, this paper concretely illustrates unintended consequences of capital control on asset prices through the collateral channel. Given that capital control is increasingly used by emerging economies as a policy tool to enhance financial stability, our results serve as a fresh reminder of the associated distortions.

# Appendix

## A Glossary of Key Model Variables

Table 6: Key model variables

Variables in the top block are exogenous; variables in the bottom block are endogenous.

| Variable | Explanation |
|---|---|
| $r^j$, $R^j$ | The secured and unsecured interest rate in country $j \in \{e, i\}$ |
| $\delta$ | Storage cost of commodity |
| $h$ | Shipping cost of commodity |
| $G_t^e$ | Commodity production of the exporting country at time $t$ |
| $k_t$, $l$ | The fundamental demander's marginal profit of using $D_t^i$ unit of commodity is $k_t - S_t^i - lD_t^i$, where $k_t \sim N(\mu_k, \sigma_k^i)$ |
| $a$, $b$ | Commodity supply in the importing country is $a + bS_t^i$ |
| $\gamma_p^e$, $\gamma_s^e$ | Risk aversion coefficients of commodity producer and financial speculator in exporting country |
| $\gamma_d^i$, $\gamma_c^i$ | Risk aversion coefficients of fundamental commodity demander and financial player in importing country |
| $S_t^j$ | Spot commodity price in period $t$ in country $j \in \{e, i\}$ |
| $F^j$ | Futures price in country $j \in \{e, i\}$, traded at $t = 0$ and delivered at $t = 1$ |
| $I_t^e$ | Commodity inventory in the exporting country at time $t$ |
| $D_{t,f}^i$, $D_{t,d}^i$ | Fundamental demand at time $t$ of foreign and domestic commodity |
| $C_0^i$ | Collateral commodity demand at time 0, all imported |
| $\lambda$ | Lagrange multiplier associated with constraint $I_0^e \geq 0$ |
| $\eta$ | Lagrange multiplier associated with constraint $D_{0,f}^i \geq 0$ |
| $h_p^e$, $h_s^e$ | Positions of futures contracts of commodity producer and financial speculator in exporting country at time 0 |
| $h_d^i$, $h_c^i$ | Positions of futures contracts of fundamental commodity demander and financial player in importing country at time 0 |
| $\sigma_S^j$ | Volatility of $S_1^j$ for $j \in \{e, i\}$ |

# B Equilibrium Solutions

For the simplicity of notations, we define the constants $(m, n, q, v, w, z, o)$ as follows:

$$
\begin{aligned}
m &= \frac{1}{\left(\sigma_S^i\right)^2}\left(\frac{\gamma_d^i+\gamma_c^i}{\gamma_d^i\gamma_c^i}\right), && (69)\\
n &= \frac{1}{\left(\sigma_S^e\right)^2}\left(\frac{\gamma_s^e+\gamma_p^e}{\gamma_s^e\gamma_p^e}\right), && (70)\\
q &= \frac{1}{2bl+1}\left[\mu_k-2al+(1-\delta)(k_0-2al)-2l\left((1-\delta)G_0^e+G_1^e\right)\right], && (71)\\
v &= \frac{(1-\delta)(2bl+1)}{2l}, && (72)\\
w &= \frac{1+R^e+r^i-R^i}{1-\delta}, && (73)\\
z &= \frac{1+r^e}{1-\delta}, && (74)\\
o &= \frac{1+R^e}{1-\delta}. && (75)
\end{aligned}
$$

## B.1 Solution to Model with Demand for Collateral Commodity (Proposition 1)

By canceling out $D_{0,f}^i$ and $D_{0,d}^i$ in the system of seven equations, we get a system of five equations:

$$
\begin{aligned}
G_0^e-I_0^e &= \left[\frac{k_0-S_0^i}{2l}-a-bS_0^i\right]+\left(\frac{\gamma_d^i+\gamma_c^i}{\gamma_d^i\gamma_c^i}\right)\frac{E\left[S_1^i-F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}, && (76)\\
I_0^e(1-\delta)+G_1^e &= \frac{\gamma_s^e+\gamma_p^e}{\gamma_s^e\gamma_p^e}\frac{E\left[S_1^e-F^e\right]}{\left(\sigma_S^e\right)^2}, && (77)\\
I_0^e(1-\delta)+G_1^e &= \frac{k_1-S_1^i}{2l}-\left(a+bS_1^i+\left(\frac{\gamma_d^i+\gamma_c^i}{\gamma_d^i\gamma_c^i}\right)\frac{E\left[S_1^i-F^i\right]}{\left(\sigma_S^i\right)^2}\right), && (78)\\
S_1^i &= S_1^e+h, && (79)\\
S_0^i &= S_0^e+h-2l\eta. && (80)
\end{aligned}
$$

Our solution strategy is to first write $S_0^e$, $S_1^e$, $S_1^i$, $F^e$ and $F^i$ as functions of $S_0^i$ and then solve for $S_0^i$.

From (78) and (79) we get

$$
\left(\sigma_S^i\right)^2=\left(\sigma_S^e\right)^2=\frac{\left(\sigma_k\right)^2}{(2lb+1)^2}. \tag{81}
$$

From (76) and (78) we get

$$\begin{aligned} E\left[S_1^i\right] &= \frac{1}{2bl+1}\left[\mu_k - 2al + (1-\delta)(k_0 - 2al) - 2l\left((1-\delta)G_0^e + G_1^e\right)\right] - (1-\delta)S_0^i \\ &= q - (1-\delta)S_0^i, && (82) \\ E\left[S_1^e\right] &= E\left[S_1^i\right] - h. && (83) \end{aligned}$$

The futures prices are given by

$$\begin{aligned} F^e &= \frac{S_0^e(1+r^e) - \lambda}{1-\delta} = \frac{\left(S_0^i - h + 2l\eta\right)(1+r^e) - \lambda}{1-\delta} && (84) \\ &= zS_0^i - hz + 2lz\eta - \frac{\lambda}{1-\delta}, && (85) \\ F^i &= \frac{\left(1 + R^e + r^i - R^i\right)}{1-\delta}S_0^i + \frac{2l(1+R^e)}{1-\delta}\eta. && (86) \end{aligned}$$

Equations (76) and (77) can be rewritten as

$$\begin{aligned} G_0^e - I_0^e &= \left[\frac{k_0 - S_0^i}{2l} - a - bS_0^i\right] + \frac{m}{(1-\delta)}E\left[S_1^i - F^i\right], && (87) \\ I_0^e(1-\delta) + G_1^e &= nE\left[S_1^e - F^e\right]. && (88) \end{aligned}$$

Substituting in the expressions of $E[S_1^e]$, $E[S_1^i]$, $F^e$ and $F^i$, we have

$$\begin{aligned} (1-\delta)G_0^e + G_1^e &= (1-\delta)\left[\frac{k_0 - S_0^i}{2l} - a - bS_0^i\right] + mE\left[S_1^i - F^i\right] + nE\left[S_1^e - F^e\right] \\ &= \frac{(1-\delta)(k_0 - 2al)}{2l} - vS_0^i && (89) \\ &\quad + mq - (1-\delta+w)mS_0^i - 2lmo\eta \\ &\quad + n(q - h + zh) - (1-\delta+z)nS_0^i - 2lnz\eta + \frac{n\lambda}{1-\delta}. \end{aligned}$$

Thus,

$$\begin{aligned} S_0^i &= \frac{\left[\begin{array}{c} \frac{(1-\delta)(k_0-2al)}{2l} + mq + n(q-h+zh) - \left[G_0^e(1-\delta) + G_1^e\right] \\ + \frac{n}{1-\delta}\lambda - 2l(om + zn)\eta \end{array}\right]}{v + (1-\delta+w)m + (1-\delta+z)n}, && (90) \\ S_0^e &= S_0^i - h + 2l\eta. && (91) \end{aligned}$$

By (76) and (78), the time-1 prices are

$$
\begin{aligned}
S_1^i &= \frac{1}{2bl+1}\left[k_1 - 2al + (1-\delta)(k_0 - 2al) - 2l\left((1-\delta)G_0^e + G_1^e\right)\right] - (1-\delta)S_0^i, \\
&= E[S_1^i] + \frac{k_1 - \mu_k}{1+2bl} = q - (1-\delta)S_0^i + \frac{k_1 - \mu_k}{1+2bl}, \qquad (92) \\
S_1^e &= S_1^i - h. \qquad (93)
\end{aligned}
$$

By (77), the inventory in the exporting country is

$$
I_0^e = \frac{1}{1-\delta}\left[n(q - h + zh) - (1-\delta+z)\,nS_0^i - G_1^e - 2nlz\eta + \frac{n\lambda}{1-\delta}\right]. \qquad (94)
$$

Furthermore,

$$
C_0^i = \frac{m}{1-\delta}\left[q - (1-\delta+w)\,S_0^i - 2lo\eta\right]. \qquad (95)
$$

**Case 1 ($\lambda = 0$ and $\eta = 0$, i.e., $I_0^e > 0$ and $D_{0,f}^i > 0$).**

In this case, the demand for collateral commodity does not lead to stockout or zero import by fundamental demanders. Since neither constraint is binding, the equilibrium prices and inventory are simply given by (41)–(45) after substituting in $\lambda = \eta = 0$. There are seven unknowns and seven linear equations, from which we obtain a unique solution.

**Case 2 ($\lambda = 0$ and $\eta > 0$, i.e., $I_0^e > 0$ and $D_{0,f}^i = 0$).**

In this case, the collateral demand leads to zero import by fundamental demanders. Intuitively, the collateral demand drives up the commodity price in the exporting country; if this price is above the spot price in the importing country after adjusting for shipping cost, the fundamental commodity demand in the importing country is met entirely by local commodity supply. In this case, the fundamental demanders import nothing, and $D_{0,f}^i$ is given by

$$
D_{0,f}^i = \frac{k_0 - 2al - (2bl+1)\,S_0^i}{2l}. \qquad (96)
$$

Thus, $D_{0,f}^i = 0$ implies that

$$
S_0^i = \frac{k_0 - 2al}{2bl+1}. \qquad (97)
$$

Therefore, given $\lambda = 0$, from (41) we can explicitly obtain $\eta$. After getting $S_0^i$ and $\eta$, we can easily solve all other variables.

**Case 3 ($\lambda > 0$ and $\eta = 0$, i.e., $I_0^e = 0$ and $D_{0,f}^i > 0$).**

In this case, the collateral demand leads to zero inventory in the exporting country. This can be the case if collateral demands drive up the price in the exporting country so much that the commodity supplier does not keep any inventory. Since $I_0^e = 0$ and

$\eta = 0$, combining (41) and (45), one can get

$$S_0^i = \frac{\frac{(1-\delta)(k_0-2la)}{2l} - G_0^e(1-\delta) + mq}{v + (1-\delta+w)m}. \tag{98}$$

Thus, combining (41) and (98), one can solve for $\lambda$. After getting $S_0^i$ and $\lambda$, all other variables can be easily solved.

**Case 4 ($\lambda > 0$ and $\eta > 0$, i.e., $I_0^e = 0$ and $D_{0,f}^i = 0$).**

In this case, too much collateral demand drives up the price in the exporting country and produces two effects. First, the commodity producer has a stockout. Second, the fundamental commodity demand in the importing country is met entirely by the cheaper local commodity supply (after adjusting for shipping cost). This corresponds to $I_0^e = 0$ and $D_{0,f}^i = 0$. As shown in Case 2, $D_{0,f}^i = 0$ implies that $S_0^i = \frac{k_0-2al}{2bl+1}$. Therefore, we have

$$\begin{aligned}
S_0^i &= \frac{\left[\begin{array}{c}\frac{(1-\delta)(k_0-2al)}{2l} + mq + n\left(q-h+zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right] \\ + \frac{n}{1-\delta}\lambda - 2l\left(om+zn\right)\eta\end{array}\right]}{v + \left(1-\delta+w\right)m + \left(1-\delta+z\right)n} = \frac{k_0-2al}{2bl+1}, \\
I_0^e &= \frac{1}{1-\delta}\left[n\left(q-h+zh\right) - \left(1-\delta+z\right)nS_0^i - G_1^e - 2nlz\eta + \frac{n\lambda}{1-\delta}\right] = 0.
\end{aligned}$$

We can solve $\lambda$ and $\eta$ from the above two equations. Then, it is easy to further solve all other variables in the equilibrium.

## B.2 Solution to the Benchmark Case (Proposition 2)

This case corresponds to $C_0^i = 0$, so equations (76)–(80) change to

$$\begin{aligned}
G_0^e - I_0^e &= \left[\frac{k_0 - S_0^i}{2l} - a - bS_0^i\right], && (99)\\
I_0^e\left(1-\delta\right) + G_1^e &= \frac{\gamma_s^e + \gamma_p^e}{\gamma_s^e\gamma_p^e}\frac{E\left[S_1^e - F^e\right]}{\left(\sigma_S^e\right)^2}, && (100)\\
I_0^e\left(1-\delta\right) + G_1^e &= \frac{k_1 - S_1^i}{2l} - \left(a + bS_1^i\right), && (101)\\
S_1^i &= S_1^e + h, && (102)\\
S_0^i &= S_0^e + h - 2l\eta. && (103)
\end{aligned}$$

The futures prices are given by

$$\begin{aligned}
F^e &= \frac{S_0^e\left(1+r^e\right) - \lambda}{1-\delta} = \frac{\left(S_0^i - h + 2l\eta\right)\left(1+r^e\right) - \lambda}{1-\delta} \\
&= \frac{1+r^e}{1-\delta}S_0^i - \frac{\left(h-2l\eta\right)\left(1+r^e\right)}{1-\delta} - \frac{\lambda}{1-\delta}, && (104)\\
F^i &= E\left[S_1^i\right], && (105)
\end{aligned}$$

where the expression of $F^i$ follows from (27), (28) and (19) after imposing $C_0^i = 0$.

Using the same constants $(n, q, v, w, z)$ defined in the previous section, following similar procedure of Proposition 1, we thus have:

$$S_0^i = \frac{\frac{(1-\delta)(k_0-2al)}{2l} + n(q-h+zh) - [G_0^e(1-\delta)+G_1^e] + \frac{n\lambda}{1-\delta} - 2nzl\eta}{v+(1-\delta+z)n}, \quad (106)$$

$$S_0^e = S_0^i - h + 2l\eta. \quad (107)$$

In this benchmark case, we restrict attention to situations in which neither the constraints binds, that is, $\eta = \lambda = 0$. Thus, the solution of the model is

$$S_0^i = \frac{\frac{(1-\delta)(k_0-2al)}{2l} + n(q-h+zh) - [G_0^e(1-\delta)+G_1^e]}{v+(1-\delta+z)n}, \quad (108)$$

$$S_0^e = S_0^i - h, \quad (109)$$

$$I_0^e = \frac{1}{1-\delta}\left[n(q-h+zh) - G_1^e - (1-\delta+z)nS_0^i\right], \quad (110)$$

$$S_1^i = E[S_1^i] + \frac{k_1-\mu_k}{2bl+1} = q-(1-\delta)S_0^i + \frac{k_1-\mu_k}{2bl+1}, \quad (111)$$

$$S_1^e = S_1^i - h = q-(1-\delta)S_0^i + \frac{k_1-\mu_k}{2bl+1} - h. \quad (112)$$

Technical Condition 2 implies that a positive quantity of commodity is imported for collateral purposes in equilibrium. Because the financial investors engaging in this trade are risk-averse, the expected marginal profit of importing commodity as collateral must be positive in equilibrium. That is, we have

$$S_0(R^i - r^i) + (1-\delta)E[S_1^i] - (S_0^e + h)(1+R^e) > 0. \quad (113)$$

Evaluating the above equation at the equilibrium prices given in Proposition 1, we have the following corollary.

**Corollary 2.** *In the equilibrium of Proposition 1,*

$$S_0^i < \frac{q - \frac{2l(1+R^e)}{1-\delta}\eta}{1-\delta+w}. \quad (114)$$

## B.3 Technical Conditions

The first restriction is that $\lambda = 0$ and $\eta = 0$ in the benchmark equilibrium with no collateral commodity. In this case, the equilibrium $S_0^i$ is given by

$$\overline{S}_0^i \equiv \frac{\frac{(1-\delta)(k_0-2al)}{2l} + n(q-h+zh) - [G_0^e(1-\delta)+G_1^e]}{v+(1-\delta+z)n}. \quad (115)$$

The restriction of $\lambda = \eta = 0$ boils down to

$$a + b\overline{S}_0^i < \frac{k_0 - \overline{S}_0^i}{2l} < G_0^e + a + b\overline{S}_0^i, \tag{116}$$

which, evaluated at the equilibrium $\overline{S}_0^i$, reduces to the following technical condition:

**Technical Condition 1.**

$$\frac{k_0 - 2la - 2lG_0^e}{1 + 2lb} < \frac{\frac{(1-\delta)(k_0 - 2al)}{2l} + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right]}{v + \left(1 - \delta + z\right)n} < \frac{k_0 - 2la}{1 + 2lb}. \tag{117}$$

Second, for the collateral channel to be nontrivial, we also restrict attention to situations in which, if demanders of collateral commodity participate in the market, they import a positive amount. This amounts to the condition that

$$\overline{S}_0^i(R^i - r^i) + (1 - \delta)E[\overline{S}_1^i] - (\overline{S}_0^e + h)(1 + R^e) > 0. \tag{118}$$

Third, the commodity producer in the importing country does not wish to keep inventory. This happens if and only if the convenience yield in the importing country in the benchmark model is nonnegative ($\overline{y}^i \geq 0$ implies $y^i \geq 0$). Thus,

$$\overline{y}^i = -\frac{q}{\overline{S}_0^i} + (1 - \delta) + \frac{1 + r^i}{1 - \delta} \geq 0. \tag{119}$$

Evaluating the above two equations at the equilibrium price $\overline{S}_0^i$, we get the following technical condition:

**Technical Condition 2.**

$$\frac{q}{1 - \delta + \frac{1 + r^i}{1 - \delta}} \leq \frac{\frac{(1-\delta)(k_0 - 2al)}{2l} + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right]}{v + \left(1 - \delta + z\right)n} < \frac{q}{1 - \delta + w}. \tag{120}$$

# C Proofs

## C.1 Proof of Proposition 3 (Prices)

1. We prove this item for the four cases one by one.

   **Case 1 ($\lambda = 0, \eta = 0$):** Technical Condition 2 implies that

$$\begin{aligned}\overline{S}_0^i &= \frac{\frac{(1-\delta)(k_0 - 2al)}{2l} + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right]}{v + \left(1 - \delta + z\right)n} \\ &< \frac{\frac{(1-\delta)(k_0 - 2al)}{2l} + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right] + mq}{v + \left(1 - \delta + z\right)n + m(1 - \delta + w)},\end{aligned}$$

where the right-hand side is the equilibrium $S_0^i$ with collateral demand. Thus, the demand for collateral commodities increases $S_0^i$ and hence $S_0^e$ (since $S_0^e = S_0^i - h$).
**Case 2 ($\lambda = 0, \eta > 0$):** In this case, the spot price $S_0^i = \frac{k_0 - 2al}{2bl+1}$, and $\eta > 0$. Technical Condition 1 implies that $\overline{S}_0^i < \frac{k_0-2al}{2bl+1} = S_0^i$. Furthermore, $\eta > 0$ implies $S_0^e = S_0^i - h + 2l\eta > S_0^i - h > \overline{S}_0^i - h = \overline{S}_0^e$.
**Case 3 ($\lambda > 0, \eta = 0$):** Similar with case 1, combined with $\lambda > 0$, Technical Condition 2 implies that

$$\begin{aligned}\overline{S}_0^i &= \frac{\frac{(1-\delta)(k_0-2al)}{2l} + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right]}{v + \left(1 - \delta + z\right) n} \\ &< \frac{\frac{(1-\delta)(k_0-2al)}{2l} + mq + n\left(q - h + zh\right) - \left[G_0^e\left(1-\delta\right) + G_1^e\right] + \frac{n}{1-\delta}\lambda}{v + \left(1-\delta+w\right) m + \left(1-\delta+z\right) n},\end{aligned}$$

where the right-hand side is the equilibrium $S_0^i$ with collateral demand. Thus, $\overline{S}_0^i < S_0^i$. Since $S_0^e = S_0^i - h$, $\overline{S}_0^e < S_0^e$.
**Case 4 ($\lambda > 0, \eta > 0$):** The proof is the same as Case 2.

2. With or without the demand for collateral commodity, we have $S_1^i = q - (1 - \delta)S_0^i + (k_1 - \mu_k)/(2bl+1)$ and $S_1^e = S_1^i - h$, both of which decrease in $S_0^i$. Thus, the demand for collateral commodity decreases the spot prices at time 1.

## C.2 Proof of Proposition 4 (Convenience Yield)

1. Holding the interest rate fixed, the convenience yield decreases in $F^j/S_0^j$ for $j \in \{e, i\}$. With collateral commodity, $F^i$ is given by

$$F^i = \frac{1 + R^e - R^i + r^i}{1-\delta} S_0^i + \frac{2l(1+R^e)}{1-\delta}\eta = wS_0^i + \frac{2l(1+R^e)}{1-\delta}\eta.$$

Without collateral commodity,

$$\overline{F}^i = q - (1-\delta)\overline{S}_0^i > q - (1-\delta)S_0^i.$$

Then, by Corollary 2,

$$F^i - \overline{F}^i < wS_0^i + \frac{2l(1+R^e)}{1-\delta}\eta - q + (1-\delta)S_0^i < 0.$$

**Case 1 ($\lambda = 0, \eta = 0$):** In the benchmark case, $\overline{F}^i = E[\overline{S}_1^i] = q - (1-\delta)\overline{S}_0^i$. Also, from previous proposition, we know $\overline{S}_0^i < S_0^i$. So,

$$\frac{\overline{F}^i}{\overline{S}_0^i} > \frac{F^i}{S_0^i} = \frac{q}{S_0^i} - (1-\delta) > w = \frac{F^i}{S_0^i},$$

where the last inequality follows from Technical Condition 2.

**Case 2** $(\lambda = 0, \eta > 0)$**:** Note that $\frac{F^i}{S_0^i} = w + \frac{2l(1+R^e)}{(1-\delta)S_0^i}\eta$. In the benchmark case, $\frac{\overline{F}^i}{\overline{S}_0^i} = \frac{q}{\overline{S}_0^i} - (1-\delta)$. But Corollary 2 implies that

$$\frac{q}{S_0^i} - (1-\delta) > w + \frac{2l\,(1+R^e)}{(1-\delta)S_0^i}\eta.$$

Hence, as $\overline{S}_0^i < S_0^i$, we have

$$\frac{\overline{F}^i}{\overline{S}_0^i} = \frac{q}{\overline{S}_0^i} - (1-\delta) > \frac{q}{S_0^i} - (1-\delta) > w + \frac{2l\,(1+R^e)}{(1-\delta)S_0^i}\eta = \frac{F^i}{S_0^i}.$$

**Case 3** $(\lambda > 0, \eta = 0)$**:** The proof is the same as Case 1.
**Case 4** $(\lambda > 0, \eta > 0)$**:** The proof is the same as Case 2.
In sum, the demand for collateral commodity makes the futures curve exhibit more backwardation, or less contango, in the importing country.

2. In Cases 1 and 2, the demand for collateral commodity does not lead to a stockout in the exporting country, which is the case here. Thus, the convenience yield remains zero in the exporting country, and $\frac{F^e}{S_0^e} = \frac{1+r^e}{1-\delta}$ does not change. In Cases 3 and 4, by (53),

$$\frac{F^e}{S_0^e} = \frac{(1+r^e)}{1-\delta} - \frac{\lambda}{S_0^e} < \frac{(1+r^e)}{1-\delta} = \frac{\overline{F}^e}{\overline{S}_0^e}.$$

Thus, the demand for collateral commodity can increases the convenience yield from zero to positive if and only if $\lambda > 0$.

## C.3 Proof of Proposition 5 (Inventory)

1. We prove this item for the four cases respectively.
**Case 1** $(\lambda = 0, \eta = 0)$**:** From (45), $I_0^e$ is linearly decreasing in $S_0^i$, so $I_0^e$ is reduced by collateral demand for commodity.
**Case 2** $(\lambda = 0, \eta > 0)$**:** From (45), $I_0^e$ is linearly decreasing in $S_0^i$ and $\eta$, so $I_0^e$ is reduced by collateral demand for commodity.
**Case 3** $(\lambda > 0, \eta = 0)$ **and Case 4** $(\lambda > 0, \eta > 0)$**:** $I_0^e = 0$, so it is smaller than that in the benchmark case.

2. This is obvious because without collateral demand the inventory in the importing country is zero.

3. Equation (33) indicates that the total inventory $I_0^e + C_0^i$ can be expressed as

$$I_0^e + C_0^i = G_1 - \frac{k_0 - 2al}{2l} + \frac{2bl+1}{2l}S_0^i$$

Since $S_0^i$ is higher with collateral demand, so is $I_0^e + C_0^i$.

## C.4 Proof of Proposition 6 (Commodity Futures Risk Premium)

From (12), one can see that the futures risk premium in the importing country $E[S_1^e - F^e]$ relates positively to the inventory level $I_0^e$. Since $I_0^e$ is smaller in the case with collateral, $E[S_1^e - F^e]$ is smaller. Furthermore, (35) and (36) show that the futures risk premium $E[S_1^i - F^i]$ is negatively correlated with the inventory level $I_0^e$ and $S_1^i$, both of which become smaller in the collateral case. Thus, $E[S_1^i - F^i]$ is larger with collateral.

## C.5 Proof of Proposition 7 (Real Demand)

1. The fundamental demand for commodities in the importing country at time 0 is $\frac{k_0 - S_0^i}{2l}$, since $S_0^i$ is smaller in the benchmark case. So the fundamental demand in the importing country is smaller in the collateral case than the benchmark case.
2. The fundamental demand for commodities in the importing country at time 1 is $\frac{k_1 - S_1^i}{2l}$, since $S_1^i$ is larger in the benchmark case. So the fundamental demand in the importing country is larger in the collateral case than the benchmark case.
3. The total fundamental demand is

$$\frac{k_0 - S_0^i}{2l} + \frac{k_1 - S_1^i}{2l} = \frac{1}{2l}\left[k_0 + k_1 - \left(S_0^i + q - (1-\delta)S_0^i + \frac{k_1 - \mu_k}{1 + 2bl}\right)\right],$$

which is decreasing in $S_0^i$. Hence, collateral demand reduces the total demand at time 0 and time 1.

## C.6 Proof of Proposition 8 (comparative statics w.r.t. $R^i$)

As $R^i$ increases, one can see that $w$ in (69) to (75) decreases, and no other parameters are affected by $w$.

1. From (41), it is easy to derive that in Case 1 of Proposition 1, a smaller $w$ causes a higher $S_0^i$. As $S_0^e = S_0^i - h$ in Case 1, a smaller $w$ also causes $S_0^e$ to increase.
2. From (33), the total inventory positively depend on $S_0^i$. Thus, a higher $R^i$ causes a higher $S_0^i$ and hence a higher total inventory. As shown in (45), the inventory in the exporting country negatively depends on $S_0^i$ and hence decreases in $R^i$. From (30), one can see that the collateral demand depends on the futures risk premium $E[S_1^i - F^i] = q - (1 - \delta + w)\, S_0^i$. It is easy to show that a smaller $w$ results in a larger $E[S_1^i - F^i]$, which in turn causes a larger collateral demand.
3. (54) shows that the convenience yield in the importing country directly depends on $R^i$; a higher $R^i$ results in a higher convenience yield.
4. As shown previously, the futures risk premium in the importing country $E[S_1^i - F^i]$ increases in $R^i$. The futures risk premium in the exporting country $E[S_1^e - F^e]$ depends on the inventory level $I_0^e$, as shown in (12). A higher $R^i$ causes a lower $I_0^e$ and hence a lower futures risk premium in the exporting country.

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