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Commodities as Collateral

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We propose and test a theory of using commodities as collateral for financing. Under capital control and collateral constraint, investors import commodities and pledge them as collateral to earn higher expected returns. Higher collateral demands increase commodity prices and make the inventory–convenience yield relation less negative. Our model illustrates these equilibrium effects and suggests that the violation of covered interest-rate parity is a proxy for collateral demands. Evidence from eight commodities in China and developed markets supports the theoretical predictions. Our findings complement the theory of storage and provide new insights into the financialization of commodity markets. (*JEL* G12, F31, F38, Q02)

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

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investors affect the price dynamics in commodity markets (see, for example, Tang and Xiong 2012; Singleton 2014; Henderson, Pearson, and Wang 2015; Cheng, Kirilenko, and Xiong 2015; and Baker 2014, among others). These studies cover a wide range of commodity markets, including spot markets, futures markets, and structured products, but none of them address the use of commodities as collateral for financing.

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 were 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 spillover into the real economy by affecting the prices of production assets.

The best market in which 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 from banks (see Elliott, Kroeber, and Qiao 2015). As a result, these firms face high unsecured interest rates.[2] Moreover, because of capital control,[3] 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. The industry estimates that in 2014 about $109 billion foreign exchange (FX) loans in China were 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]

[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 rate on private borrowing is about 20% in the Wenzhou metropolitan area, which is an entrepreneurial hub in the southeast of China. See http://www.wzmjjddj.com/news/bencandy.php?fid=97&id=2333 (Chinese language website).

[3] The capital inflows to China's financial markets from abroad are controlled by the "Qualified Foreign Institutional 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 Reuters, as of November 2015, the overall quota for all QFIIs was just below $80 billion (see http://www.reuters.com/article/china-investment-qfii-idUSL3N13P3C720151130). Note that this amount is smaller than China's FX loan volume backed by commodities, as estimated by the industry. 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. Economic Observer (2012) estimates that 90% of copper stored in the tariff-free zone in Shanghai is for financing purposes, with the total amount more than 500,000 tons. Shanghai Metals Market, a research firm, estimates that between 400,000 and 600,000 tons of copper have been used for financing in China

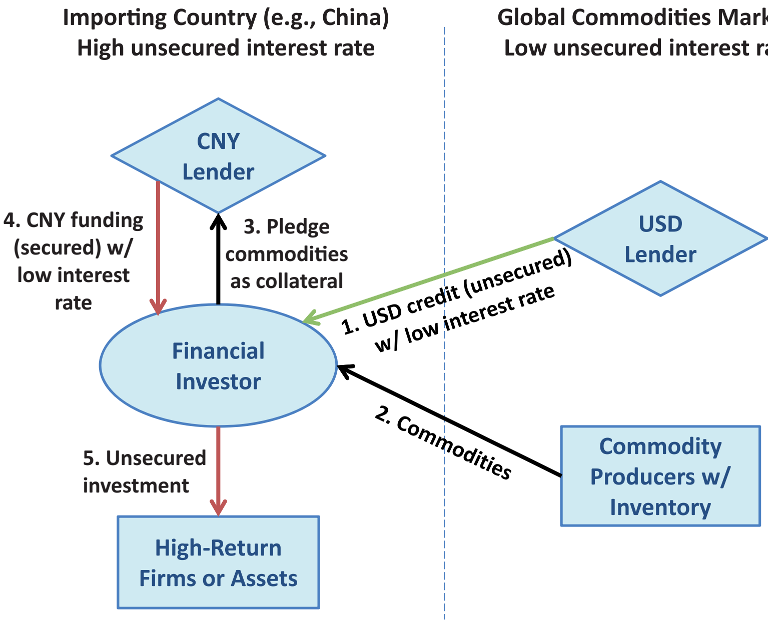

Figure 1
A typical process of commodity-based financing

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 and not counted as capital flow.

When the importing country has a sufficiently high unsecured interest rate relative to the exporting country, after hedging foreign exchange risk, collateral demands for commodities emerge endogenously. 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 1). In period 0 they borrow U.S. dollars (USD) 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

in 2013. To put these estimates into perspective, a half-million tons of copper accounted for approximately 5.7% of China's annual copper consumption and accounted for 2.4% of the world's consumption in 2012.

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 constraints. In period 1 all borrowing and lending are unwound, and the collateral commodity is sold to the fundamental consumer. The financial investor can use the futures market in the importing country to hedge commodity price risk. The financial investor can also trade currency forward in the foreign exchange market to hedge currency risk (because borrowed funds are in USD and investment returns are in Chinese Yuan [CNY]).

We characterize the equilibrium in which commodities are imported both for fundamental consumption and as financing collateral. The model reveals that the collateral demand for commodities has a number of important implications. For example, an increase in collateral demand leads to an increase in concurrent commodity prices in both the importing and exporting countries; a decrease in collateral demand does the opposite. The model also predicts that a higher collateral demand simultaneously increases inventory and convenience yield in the importing country; a decrease in collateral demand simultaneously reduces inventory and convenience yield. This comovement is complementary to the theory of storage, which predicts that inventory and convenience yield should move in opposite directions. To the best of our knowledge, our theory is the only one that predicts a positive relation (conditional on all else) between inventory and convenience yield.

We test the model's 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 China and the exporting country is developed markets (e.g., the United States, the United Kingdom, Japan). Our sample consists of weekly observations of prices and inventories from October 13, 2006, to November 14, 2014. We test how collateral demand for commodities affects (i) commodity prices and (ii) 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 stronger 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, model-implied empirical measure: the forward-hedged interest-rate spread, which has the following form:

$$Y = (1+R_{CNY}) - \frac{\text{USDCNY Forward}}{\text{USDCNY Spot}}(1+R_{USD}), \tag{1}$$

where R_{CNY} is the unsecured interest rate in CNY, China's currency, and R_{USD} is the unsecured interest rate in USD. In the commodity collateral trade, borrowed funds in USD at the rate R_{USD} are converted to CNY at the spot exchange rate, and invested in China at the expected return R_{CNY}; simultaneously, the principal plus interest on the USD loan, $1+R_{USD}$, are also converted to CNY at the forward exchange rate. Thus, by using commodities, the financial investors effectively circumvent capital control and bring in funds to get higher expected returns in China, after hedging currency risk. The other part of the profit in importing commodities as collateral involves changes in commodity prices and storage costs, but that part is standard and applies without capital control.

The true unsecured interest rates, R_{CNY} and R_{USD}, at which the financial investors lend and borrow are unobservable, but the unsecured interbank rates are observable. We therefore construct the following empirical proxy for collateral demand:

$$\hat{Y} = (1+Shibor) - \frac{\text{USDCNY Forward}}{\text{USDCNY Spot}}(1+Libor), \tag{2}$$

where Shibor is the Shanghai Interbank Offered Rate in CNY and Libor is the London Interbank Offered Rate in USD. We elaborate in the data section why interbank rates are better than some alternatives. The two exchange rates are the official spot exchange rate and nondeliverable forward (NDF).[5] $\hat{Y}$ constructed this way can also be viewed as the violation of the covered interest-rate parity, calculated using interbank rates. Without capital control, $\hat{Y}$ should be close to zero. But with capital controls, $\hat{Y}$ may persistently stay away from zero. In the data, we find that $\hat{Y}$ is positive most of the time, implying a positive expected profit for importing commodities as collateral. The more positive is $\hat{Y}$, the more attractive it is to import commodities as collateral.

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; a lower collateral demand of course does the opposite. The economic magnitude is also large. A one-standard-deviation increase in collateral demand (proxied by $\hat{Y}$) increases the contemporaneous metal prices by about 3% in China and about 4% in developed markets. This increase is the largest for copper traded on the London Metal Exchange, by about 5.3%. Reactions of nonmetal prices are smaller, at about 1.3% in China and 2.9% in developed markets, for the same one-standard-deviation change in collateral demand. These estimates remain significant and have almost the same magnitude if China's macroeconomic fundamentals are included as control variables.

In the second test, we find that a higher collateral demand for commodities makes the inventory–convenience yield relation significantly less negative in

[5] 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 CNY is not freely convertible and physical delivery is difficult. 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 on the USDCNY NDF, see Yu (2007) and Asia Securities Industry and Financial Markets Association (2014).

China for metals. This test distinguishes our theory from the theory of storage, which predicts that inventory and convenience yield should 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. Inclusion of China's macroeconomic fundamentals as control variables affects neither the statistical significance nor the economic magnitude of the estimates.

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's (2015) 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 global economic fundamentals turned out to be weak.

Another implication of our result is that collateral demand may lead to "excess volatility" in commodity prices beyond economic fundamentals. Indeed, we find that collateral demand and China's macroeconomic fundamentals operate in a nonoverlapping fashion in driving commodity prices. Moreover, since our proxy for collateral demand $\hat{Y}$ is mean-reverting, the evidence on prices is best interpreted as a temporary price effect, lasting for a couple of years, rather than a permanent price effect, lasting for decades.

While the institutional settings of this paper are modeled after China, the essential friction of capital control is more widespread. For example, since the global financial crisis, various forms of capital control have been imposed in Brazil, India, South Korea, Indonesia, Ukraine, and Iceland, among others (see International Monetary Fund 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 collateral demand for commodities can partly crowd out 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 trade-off 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. 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 (2015) 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 of 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 commodities, which is a novel contribution to the literature.

Our theory and empirical findings are complementary to the classical theory of storage (see Working 1960; Telser 1958; Brennan 1958; Routledge, Seppi, and Spatt 2000; Pindyck 2001; and Gorton, Hayashi, and Rouwenhorst 2013, among others). For example, while the theory of storage predicts a negative relation between convenience yield and inventory, our model predicts that collateral demands for commodities simultaneously raise inventory and convenience yield, a positive relation. Moreover, collateral demands simultaneously result in a high total inventory and a high commodity price. This is again opposite to the prediction from the theory of storage that an increased inventory indicates the abundance of the commodity and hence a lower price.

1. 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. For more details on international trade finance in general, see Moffett, Stonehill, and Eiteman (2011, Chapter 19).

A typical commodity financing transaction consists of a few steps.[6] First, a Chinese importing firm signs a contract to buy a 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.[7] The letter of credit is typically granted in USD at the USD interest rate and guarantees

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

7 Sometimes two banks are involved in this process. One is the importer's bank and the other is the exporter's bank.

that the seller will be paid by the bank.[8] To obtain 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 and six months. For example, if the letter of credit 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 the commodity to bonded warehouses in China's ports and obtains a warehouse receipt. Note that at this stage the commodity stored at a bonded warehouse has not yet entered the Chinese customs, and the importer has not paid 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 commodity collateral to capture the spread between the secured and unsecured CNY funding rates in China.

Third, before the USD and CNY loans mature, the commodity importer receives the unsecured return from its CNY investments and then sells the commodity stored in the bonded warehouse in China's ports. The importer also closes its futures position. The proceeds of the 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 or domestic bank for the letter of credit (with relatively low USD interest rates). 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. 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 resell the commodity in the 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 are 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

[8] Banks involved in commodity trade financing include BNP Paribas, Crédit Agricole, ING, Société Générale, JPMorgan, Citigroup, Standard Chartered, and HSBC, among others. J. Blas and A. Makan,"Banks return to commodities finance," *Financial Times*, February 5, 2013.

importing additional commodities, instead of recycling existing commodities in bonded warehouses.

As we discussed earlier, 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 because they lack 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 unsecured interest rate in China, compared with developed economies. Importing commodities as collateral is a direct consequence of these frictions.[9]

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 provide 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 was due that Friday.[10] Following this announcement, the global benchmark copper price traded on LME tumbled by more than 8.5% over a week, from $7,102.5/ton on March 5 to $6,498/ton on March 12. Although the Chaori default is relatively small, it was the first ever Chinese corporate bond default, and it 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.[11]

The second event is the probe by Chinese authorities of alleged frauds in the port of Qingdao (in northern China) that some lenders may have pledged the same commodities to multiple banks to get multiple loans.[12] LME copper prices dropped by about 4% from $6,930/ton on June 3 to $6,660.5/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

[9] Moreover, the use of commodities as collateral may be viewed as part of China's "shadow banking"—that is, lending by non-bank institutions to borrowers who need credit. Elliott, Kroeber, and Qiao (2015) provide an excellent overview of the current practice of shadow banking in China, including loans and leases by trust companies, entrusted loans, microfinance companies, and wealth management products, among others. These activities are predominantly domestic, concerned with how to bring capital to those who need it within China. An important distinction of importing commodities as collateral is that it brings in international capital by circumventing capital control through commodities. Once the commodities are imported and pledged to obtain low-interest CNY loans, the use of the proceeds can be viewed as part of the "domestic" shadow-banking activity.

[10] G. Wildau and U. Desai, "China's Chaori Solar poised for landmark bond default," *Reuters*, March 5, 2014.

[11] X. Rice, J. Smyth, and L. Hornby, "Copper futures fall by daily limit," *Financial Times*, March 12, 2014. I. Iosebashvili and T. Shumsky, "China angst slams prices for copper," *Wall Street Journal*, March 10, 2014.

[12] S. Thomas, "Standard Bank starts probe of potential irregularities at China port," *Reuters*, June 4, 2014.

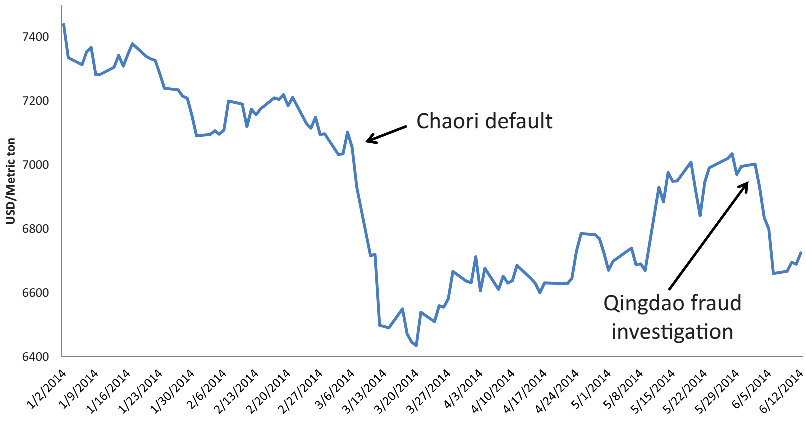

Figure 2
LME copper prices around two China-specific events

requirements, such as a higher haircut. This, in turn, reduces the attractiveness of importing commodity as collateral and associated commodity prices.[13]

2. A Model of Commodities as Collateral

In this section we present a 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.

The commodity is priced in USD in the exporting country and priced in the local currency (e.g., CNY) in the importing country. Expressed in units of local currency per USD, in period $t \in \{0,1\}$, the spot exchange rate is X_t. The forward exchange rate is f_X in period 0. 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 segmented. In particular, the covered interest rate parity may or may not hold.

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

The rest of this section describes the model components in detail. The last subsection, Section 2.8, discusses our modeling choices and potential

13 F. Wong and M. Serapio Jr., "Worry plagues commodity finance trade after Chinese metals probe," *Reuters*, June 8, 2014.

alternative approaches. Equilibrium solutions and implications are presented in Section 3.

2.1 The 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 (2013). 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) is fixed ex ante and is 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,

$$Q_0^e = G_0^e - I_0^e, \tag{3}$$

$$Q_1^e = G_1^e + (1-\delta)I_0^e. \tag{4}$$

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

$$W_p^e = S_0^e(G_0^e - I_0^e)(1+r^e) + S_1^e(G_1^e + (1-\delta)I_0^e) - h_p^e(S_1^e - F^e), \tag{5}$$

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 σ_S^e the volatility (standard deviation) of S_1^e.

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

$$E[W_p^e] - \frac{\gamma_p^e}{2}\mathrm{Var}[W_p^e]. \tag{6}$$

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

$$\max_{\{I_0^e, h_p^e\}} S_0^e\left(G_0^e - I_0^e\right)(1+r^e) + E\left[S_1^e((1-\delta)I_0^e + G_1^e) - h_p^e\left(S_1^e - F^e\right)\right]$$

$$-\frac{\gamma_p^e}{2}\mathrm{Var}\left[S_1^e((1-\delta)I_0^e + G_1^e) - h_p^e\left(S_1^e - F^e\right)\right], \tag{7}$$

$$\text{subject to} \quad I_0^e \geq 0.$$

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

$$I_0^e = \frac{E\left[S_1^e\right](1-\delta) - S_0^e(1+r^e)+\lambda}{\gamma_p^e\left(\sigma_S^e\right)^2(1-\delta)^2} + \frac{h_p^e - G_1^e}{(1-\delta)}, \tag{8}$$

$$h_p^e = I_0^e(1-\delta)+G_1^e - \frac{E\left[S_1^e - F^e\right]}{\gamma_p^e\left(\sigma_S^e\right)^2}. \tag{9}$$

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

2.2 The speculator in the exporting country

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

$$\max_{h_s^e} E\left[h_s^e\left(S_1^e - F^e\right)\right] - \frac{\gamma_s^e}{2}\text{Var}\left[h_s^e\left(S_1^e - F^e\right)\right]. \tag{10}$$

The solution is

$$h_s^e = \frac{E\left[S_1^e - F^e\right]}{\gamma_s^e\left(\sigma_S^e\right)^2}. \tag{11}$$

2.3 Market clearing in the exporting country

From Equations (8) and (9), we obtain

$$\frac{S_0^e - F^e}{S_0^e} = \frac{\lambda}{S_0^e(1-\delta)} - \frac{r^e+\delta}{1-\delta}. \tag{12}$$

Thus, the futures price in the exporting country is

$$F^e = \frac{S_0^e(1+r^e)-\lambda}{1-\delta}, \tag{13}$$

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

$$E\left[S_1^e - F^e\right] = \frac{\gamma_s^e\gamma_p^e}{\gamma_s^e+\gamma_p^e}\left(\sigma_S^e\right)^2[I_0^e(1-\delta)+G_1^e]. \tag{14}$$

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.

2.4 The producer in the importing country

Symmetric to the exporting country, the commodity productions in the importing country in the two periods are given by $Q_0^i = a_0$ and $Q_1^i = a_1$, respectively, where a_0 and a_1 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 period 0 and period 1. The condition is provided in the characterization of equilibrium. Relaxing this parameter condition does not change the qualitative nature of the results.

2.5 The fundamental consumer in the importing country

We model the "fundamental consumer" in the importing country as a consumer who uses the commodity as an input to produce final goods. In period t, the fundamental consumer has a linearly decreasing average profit per unit of commodity input, expressed in local currency:

$$k_t - S^i_t - l D^i_t, \tag{15}$$

where k_t is a random variable, l is a constant, and D^i_t is the amount of commodity input used at time t. In period 0, k_0 is commonly known, but k_1 is unobservable and has a mean of μ_k and a variance of σ_k^2. This stochastic k_1 can be interpreted as the "fundamental shock" to the economy of the importing country, only realized in period 1. All players in our model have symmetric information and the same probability distribution about k_1. The fundamental consumer has the mean-variance preference with parameter γ^i_d.

The fundamental consumer has three endogenous decisions in period 0: the amount of commodities to import, $D^i_{0,f}$; the amount of commodities to buy in the domestic market, $D^i_{0,d}$; and the amount of commodity futures contracts to buy in the local market, h^i_d. The shipment of one unit of the commodity across the two countries incurs the cost, in USD, of $h>0$. For simplicity, shipment is instantaneous; that is, a commodity purchased in the exporting country at time t can be used in the importing country at time t as well. Also for simplicity, we assume that the fundamental consumer does not hedge FX exposures and will convert local currency to USD at the exchange rate X_1 in period 1.[14]

The terminal wealth of the fundamental consumer consists of two parts. The first part, denoted by $W^i_{d,0}$, comes from the production profit in period 0 (adjusted by interest) and the realized trading profits in commodity futures. Thus,

$$\begin{aligned} W^i_{d,0} = {} & D^i_{0,f}\left[k_0 - \left(S^e_0 + h\right)X_0 - l\left(D^i_{0,f} + D^i_{0,d}\right)\right]\left(1+r^i\right) \\ & + D^i_{0,d}\left[k_0 - S^i_0 - l\left(D^i_{0,f} + D^i_{0,d}\right)\right]\left(1+r^i\right) + h^i_d\left(S^i_1 - F^i\right), \end{aligned} \tag{16}$$

where r^i is the secured interest rate in the importing country. The first and second terms of $W^i_{d,0}$ are, respectively, the fundamental consumer's production profits of using foreign and domestic commodity supplies, adjusted by interest. The third term is the trading profit in the commodity futures market.

The second part of the fundamental consumer's terminal wealth is the production profit in period 1, denoted by $W^i_{d,1}$. We denote by $D^i_{1,f}$ and $D^i_{1,d}$ the

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[14] Since the fundamental consumer's foreign commodity demand in period 1 depends on the realized shock k_1, this demand cannot be perfectly forecasted or hedged in period 0. Thus, even if the fundamental consumer hedges a constant quantity of the commodity in period 0, he is still subject to FX risk in period 1 with probability 1. Thus, for simplicity, we assume zero FX hedge. Note that the fundamental consumer's wealth in period 1 is not affected by FX hedging.

period 1 demands for foreign and domestic commodities, respectively. Then,

$$W^i_{d,1}=D^i_{1,f}\left[k_1-\left(S^e_1+h\right)X_1-l(D^i_{1,f}+D^i_{1,d})\right]+D^i_{1,d}\left[k_1-S^i_1-l(D^i_{1,f}+D^i_{1,d})\right], \tag{17}$$

We solve the fundamental consumer's problem backward in time. In period 1, since the fundamental shock k_1 is realized and becomes common knowledge, the fundamental consumer solves

$$\max_{\left\{D^i_{1,d},D^i_{1,f}\right\}} W^i_{d,1}, \tag{18}$$

where there is no variance term since S^i_1 becomes known in period 1.

The solution is

$$D^i_{1,d}=\frac{k_1-S^i_1}{2l}-D^i_{1,f}, \tag{19}$$

$$D^i_{1,f}=\frac{k_1-\left(S^e_1+h\right)X_1}{2l}-D^i_{1,d}. \tag{20}$$

Substituting the solution into the fundamental consumer's wealth $W^i_{d,1}$, we get

$$W^i_{d,1}=\frac{(k_1-S^i_1)^2}{4l}. \tag{21}$$

Moreover, by market-clearing, $D^i_{1,d}+D^i_{1,f}=a_1+G^e_1+(1-\delta)I^e_0$, which is a constant known in period 0. Thus, by Equation (19), we know that $k_1-S^i_1$ is a constant as well. Hence, $W^i_{d,1}$ is a constant, viewed in period 0.

Now, moving back to period 0, the fundamental consumer solves

$$\max_{\left\{D^i_{0,d},D^i_{0,f},h^i_d\right\}} E[W^i_{d,0}+W^i_{d,1}]-\frac{\gamma^i_d}{2}\text{Var}[W^i_{d,0}+W^i_{d,1}], \tag{22}$$

$$\text{subject to} \quad D^i_{0,f}\geq 0. \tag{23}$$

But because $W^i_{d,1}$ is a constant, the fundamental consumer's period 0 problem reduces to

$$\max_{\left\{D^i_{0,d},D^i_{0,f},h^i_d\right\}} E[W^i_{d,0}]-\frac{\gamma^i_d}{2}\text{Var}[W^i_{d,0}], \tag{24}$$

$$\text{subject to} \quad D^i_{0,f}\geq 0.$$

The first-order conditions yield

$$D^i_{0,f} = \frac{k_0 - \left(S^e_0 + h\right) X_0}{2l} - D^i_{0,d} + \eta, \tag{25}$$

$$D^i_{0,d} = \frac{k_0 - S^i_0}{2l} - D^i_{0,f}, \tag{26}$$

$$h^i_d = \frac{E\left[S^i_1 - F^i\right]}{\gamma^i_d \left(\sigma^i_S\right)^2}, \tag{27}$$

where σ^i_S is the volatility of S^i_1 and η is the Lagrange multiplier associated with the constraint (23). If $D^i_{0,f} = 0$, that is, the fundamental consumer only buys the commodity locally, then $\eta > 0$. If $D^i_{0,f} > 0$, then $\eta = 0$.

2.6 The financial investor in the importing country

The financial investor in the importing country imports the 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 investor must first borrow an unsecured loan in the exporting country at the rate R^e to pay for the costs of the commodity and shipping. Since borrowing and lending take one period, this trade must be completed in period 0. We also assume that the financial investor purchases, in period 0 and at the forward exchange rate f_X, an amount of USD that covers the principal and interest payment of the USD loan, so that there remains no currency risk.

The expected period 1 profit of importing one unit of collateral commodity in period 0, expressed in local currency, is

$$\Pi = S^i_0(R^i - r^i) + (1-\delta) E[S^i_1] - \left(S^e_0 + h\right)(1 + R^e) f_X. \tag{28}$$

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 in period 1, and the payment of the unsecured loan at rate R^e after converting to local currency. We later specify the condition under which the expected profit of importing the commodity as collateral is positive. We denote by C^i_0 the amount of the commodity imported for collateral purposes in period 0.

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

The financial investor also uses futures contracts to hedge his inventory of collateral commodity. We denote by h^i_c his short futures position in period 0.

The financial investor's terminal wealth in period 1, in local currency, is

$$W_f^i = C_0^i\left[S_0^i(R^i - r^i) + (1-\delta)S_1^i - \left(S_0^e + h\right)(1+R^e)f_X\right] - h_c^i(S_1^i - F^i). \quad (29)$$

The financial investor has a mean-variance utility function with parameter γ_c^i. In period 0, he solves the problem

$$\max_{\left\{C_0^i, h_c^i\right\}} E[W_f^i] - \frac{\gamma_c^i}{2}\mathrm{Var}[W_f^i], \quad (30)$$

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

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

$$C_0^i = \frac{S_0^i(R^i - r^i) + (1-\delta)E\left[S_1^i\right] - \left(S_0^e + h\right)(1+R^e)f_X}{\gamma_c^i\left(\sigma_S^i\right)^2(1-\delta)^2} + \frac{h_c^i}{1-\delta}, \quad (31)$$

$$h_c^i = -\frac{E\left[S_1^i - F^i\right]}{\gamma_c^i\left(\sigma_S^i\right)^2} + C_0^i(1-\delta). \quad (32)$$

2.7 Market clearing in the importing country

From Equations (25) and (26), we get

$$S_0^i = (S_0^e + h)X_0 - 2l\eta. \quad (33)$$

Recall that η 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 Equations (19) and (20), we get

$$S_1^i = (S_1^e + h)X_1.$$

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

$$C_0^i = \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i\gamma_c^i}\right)\frac{E\left[S_1^i - F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}. \quad (34)$$

For parameters considered in this paper, $C_0^i > 0$. From Equations (31) and (32), we can solve the futures price in the importing country,

$$F^i = \frac{\left(S_0^e + h\right)(1+R^e)f_X}{1-\delta} - \frac{S_0^i\left(R^i - r^i\right)}{1-\delta} \quad (35)$$

$$= \frac{\frac{f_X}{X_0}(1+R^e) - (R^i - r^i)}{1-\delta}S_0^i + \frac{f_X}{X_0}\frac{2l(1+R^e)}{1-\delta}\eta.$$

2.8 A discussion of the 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 segmented; 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 financial investors can also trade futures contracts in the exporting country, they would not import commodities. Thus, capital control and the effective segmentation of financial markets are essential frictions 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. But like many two-period models, our two-period model is meant to illustrate the intuition in a tractable way, but not a literal description of reality. Period 1 can be viewed as an abstract future date when market conditions are such that importing commodities as collateral is no longer profitable. One example of that future date is when (if ever) China drops its capital control.

3. Equilibrium and Comparative Statics

In this section we characterize the equilibrium prices and quantities, as well as the comparative statics with respect to the unsecured interest rate in the importing country, R^i. The analysis of this section lays down the foundation for empirical tests conducted in the next section.

3.1 Equilibrium characterization

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

Proposition 1. Under Technical Conditions 1–3 provided in Appendix B.1, 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:

$$D_{0,d}^i = a_0, \tag{36}$$

$$G_0^e - I_0^e = D_{0,f}^i + C_0^i$$
$$= \left[\frac{k_0 - \left(S_0^e + h\right) X_0}{2l} - D_{0,d}^i + \eta \right] + \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i} \right) \frac{E\left[S_1^i - F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}, \tag{37}$$

$$E\left[S_1^e - F^e\right] = \frac{\gamma_s^e \gamma_p^e}{\gamma_s^e + \gamma_p^e} \left(\sigma_S^e\right)^2 [I_0^e(1-\delta) + G_1^e], \tag{38}$$

$$D_{1,d}^i = a_1 + \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right) \frac{E\left[S_1^i - F^i\right]}{\left(\sigma_S^i\right)^2}, \tag{39}$$

$$\begin{aligned} I_0^e(1-\delta) + G_1^e &= D_{1,f}^i \\ &= \frac{k_1 - \left(S_1^e + h\right) X_1}{2l} - D_{1,d}^i, \end{aligned} \tag{40}$$

$$S_1^i = (S_1^e + h) X_1, \tag{41}$$

$$S_0^i = (S_0^e + h) X_0 - 2l\eta, \tag{42}$$

where

$$F^e = \frac{S_0^e(1+r^e) - \lambda}{1-\delta}, \tag{43}$$

$$F^i = \frac{(S_0^e + h)(1+R^e) f_X - S_0^i (R^i - r^i)}{1-\delta}. \tag{44}$$

The two Lagrange multipliers (λ, η) satisfy:

$$\text{if } I_0^e = 0, \lambda > 0,$$
$$\text{if } I_0^e > 0, \lambda = 0,$$

and

$$\text{if } D_{0,f}^i = 0, \eta = D_{0,d}^i - \frac{k_0 - \left(S_0^e + h\right) X_0}{2l} > 0,$$
$$\text{if } D_{0,f}^i > 0, \eta = 0.$$

The solutions of spot prices and inventories are:

$$S_0^i = \frac{\left[\begin{array}{c} \frac{(1-\delta)(k_0 - 2a_0 l)}{2l} + mq + n(b - h + zh) - \left[G_0^e(1-\delta) + G_1^e\right] \\ + \frac{n}{1-\delta}\lambda - 2l(om + zn/X_0)\eta \end{array}\right]}{v + (1-\delta+w)m + ((1-\delta)/u_X + z/X_0)n}, \tag{45}$$

$$S_0^e = \frac{S_0^i + 2l\eta}{X_0} - h. \tag{46}$$

$$S_1^i = q + k_1 - \mu_k - (1-\delta) S_0^i, \tag{47}$$

$$S_1^e = \frac{S_1^i}{X_1} - h, \tag{48}$$

$$I_0^e = \frac{1}{1-\delta}\left[n(b-h+zh)-((1-\delta)/u_X+z/X_0)nS_0^i - G_1^e - 2nlz\eta/X_0 + \frac{n\lambda}{1-\delta}\right], \tag{49}$$

where the constants (m,n,q,b,v,w,z,o) are defined in Appendix B. The equilibrium demands $(C_0^i, D_{0,d}^i, D_{1,d}^i, D_{0,f}^i, D_{1,f}^i)$ are calculated from Equations (36)–(40).

The technical conditions for Proposition 1 imply the following two properties of the equilibrium. First, collateral demand for commodity, C_0^i, is positive in equilibrium.[15] Second, the commodity producer in the importing country does not wish to carry inventory. Relaxing this condition will lead to more parameter cases but does not change the qualitative nature of the results.

The solution in Proposition 1 involves two Lagrange multipliers, λ and η. Depending on whether they are zero or positive, there are four cases of equilibrium:

Case 1. $\lambda=0$ and $\eta=0$, that is, $I_0^e>0$ and $D_{0,f}^i>0$. In this case, the exporting country does not have a stockout, and the fundamental consumer uses both domestic and foreign commodities.

Case 2. $\lambda=0$ and $\eta>0$, that is, $I_0^e>0$ and $D_{0,f}^i=0$. In this case, the exporting country does not have a stockout, but the fundamental consumer uses only domestic commodities. This is because collateral demand is so strong that $(S_0^e+h)X_0>S_0^i$.

Case 3. $\lambda>0$ and $\eta=0$, that is, $I_0^e=0$ and $D_{0,f}^i>0$. In this case, the exporting country has a stockout, but the fundamental consumer uses both domestic and foreign commodities.

Case 4. $\lambda>0$ and $\eta>0$, that is, $I_0^e=0$ and $D_{0,f}^i=0$. In this case, the exporting country has a stockout, and the fundamental consumer uses only domestic commodities.

The explicit solutions for the four cases are provided in Appendix B.

3.2 Comparative statics

We now characterize the comparative statics of equilibrium variables to the unsecured interest rates R^i in the importing country.

Proposition 2. Fixing other parameters, if the unsecured interest rate R^i increases in the importing country, then S_0^i, S_0^e, C_0^i, and y_i have the following

15 The case of equilibrium with zero collateral demand can be obtained in a similar fashion, and is available upon request.

comparative statics in Cases 2, 3, and 4 of Proposition 1:

	Case 2	Case 3	Case 4
S_0^i	flat ($=k_0-2a_0l$)	increase	flat ($=k_0-2a_0l$)
S_0^e	increase	increase	increase
C_0^i	increase	increase	flat ($=G_0^e$)
y^i	increase	increase	flat

In Case 1 of Proposition 1, in the limit that γ_s^e converges to zero, an increase in R^i leads to increases in C_0^i and y^i, and S_0^i and S_0^e are invariant to changes in R^i.

The easiest way to discuss the intuition behind these comparative statics is to go backward, from Case 4 to Case 1 (for proof, see Appendix B). In Case 4, the exporting country has a stockout and the fundamental consumer in the importing country uses only local commodities. The entire commodity supply in the exporting country, G_0^e, is bought by the financial investor as collateral. The commodity price in the importing country, S_0^i, depends only on local supply and fundamentals. Thus, a higher R^i cannot affect S_0^i or C_0^i, as these two variables already hit a corner solution. The convenience yield in the importing country is given by

$$y_i = -\frac{F^i}{S_0^i} + \frac{1+r^i}{1-\delta} = \frac{(1+R^i) - \frac{f_X}{X_0}(1+R^e)}{1-\delta} - \frac{2l}{S_0^i}\frac{1+R^e}{1-\delta}\frac{f_X}{X_0}\eta. \tag{50}$$

Appendix B shows that the equilibrium η increases in R^i with such a proportion that y^i is also invariant to R^i. The fact that η increases in R^i also implies that S_0^e increases in R^i since $S_0^e = (S_0^i + 2l\eta)/X_0 - h$.

Case 3 shares the feature with Case 4 that the exporting country has a stockout, but the total supply G_0^e in the exporting country is shared by the fundamental consumer and the financial investor in the importing country. As R^i increases, the financial investor's profit for importing commodities as collateral increases, so his demand goes up, pushing up his inventory C_0^i and the commodity price S_0^e in the exporting country. The fundamental consumer, in turn, switches partly to domestic commodities, pushing up price S_0^i in the importing country as well. Since $\eta = 0$ in this case, Equation (50) reveals that the convenience yield in the importing country is proportional to the forward-hedged interest-rate spread:

$$Y \equiv (1+R^i) - \frac{f_X}{X_0}(1+R^e), \tag{51}$$

which is obviously increasing in R^i.

Case 2 shares the feature with Case 4 that $S_0^i = k_0 - 2a_0l$, since the fundamental consumer in the importing country uses only local commodities. But the exporting country still carries positive inventory. As R^i increases, the financial investor is able to purchase and import more commodities as collateral. A higher collateral demand pushes up S_0^e, C_0^i, and y^i.

Case 1 is the most complicated case from a technical viewpoint (see Appendix B for details), but comparative statics are easy to obtain in the limit of $\gamma_s^e \to 0$, that is, the speculator in the commodity futures market in the exporting country is close to being risk-neutral. Although the risk-neutral assumption here is not without loss of generality, it is a reasonable one to obtain tractability. For instance, the existing empirical studies find mixed evidence on whether speculators earn significant excess returns by buying commodity futures (see Section 5.3 for a discussion). In this limiting case, the commodity supplier in the exporting country hedges the entire inventory and future production, $(1-\delta)I_0^e + G_1^e$, but pays zero risk premium to do so. An increase in R^i still leads to a higher collateral demand C_0^i and a higher convenience yield y^i, but commodity prices S_0^i and S_0^e are invariant to R^i.

Proposition 2 immediately implies the following useful corollary:

Corollary 1. Fixing other parameters, a higher unsecured interest rate R^i in the importing country makes the relation between inventory and convenience yield more positive (or less negative) in the importing country.

Note that the theory does not make a prediction on the inventory–convenience yield relation in the exporting country. In the model, the convenience yield in the exporting country $y^e = \frac{\lambda}{(1-\delta)S_0^i}$ is positive if the inventory $I_0^e = 0$; and I_0^e is positive if $y^e = 0$. So y^e and I_0^e have no significant covariation in the model, regardless of the level of R^i.

3.3 Discussion

Our finding 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, 2006) shows 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 U.S. interest rate, representing global monetary policy, as well as on the real interest rate differential between non-U.S. countries and the United States, representing local variations in monetary policy.

Complementary to Frankel's work, our result focuses on the collateral role of commodities as a device to circumvent capital control. In this case, a higher unsecured interest rate can counterintuitively increase the demand for collateral and hence increase the global price of commodities.

The collateral use of commodities in our model complements 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 as a large, persistent shock to the prices of assets and firms' investments and production. Our model is complementary in that the production asset, the commodity, is a traded asset, and firms not involved in the real production can also import the commodity to generate financial returns. In our model, if the production functions of the real sector are invariant to the interest rate, more financial demand for the commodity can crowd out the real demand by increasing commodity spot prices and by increasing the deadweight loss of commodity storage.[16] If, however, the production constraint can be relaxed by importing commodities as collateral, we may reasonably expect the collateral demand for commodities 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 are therefore ambiguous.

4. Data

This section describes the data and empirical measures used to test the model predictions.

4.1 A proxy for collateral demand of commodities

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

Recall from Equation (28) that the expected profit (in local currency) of importing one unit of commodity and using it as collateral, before hedging commodity price risk, is

$$\Pi = S_0^i(R^i - r^i) + (1-\delta)E[S_1^i] - (S_0^e + h)(1+R^e)f_X. \quad (52)$$

Again, the first term is the profit of borrowing at the secured rate r^i and investing at the expected return R^i; the second term is the expected proceeds of selling the inventory in period 1; and the third term is the repayment of borrowed funds in USD converted into CNY at the forward exchange rate.

In Case 1 and Case 3 of the equilibrium, $S_0^i = (S_0^e + h)X_0$, so Π can be reexpressed as

$$\Pi = S_0^i Y + (1-\delta)E[S_1^i] - (1+r^i)S_0^i, \quad (53)$$

[16] In the model, one can show that if R^i is higher, then the fundamental consumer of the commodity consumes less of the commodity in period 0 and more of the commodity in period 1; overall, the fundamental consumption of the commodity goes down because of a larger storage cost, δC_0^i, associated with a larger inventory.

where (recalling)

$$Y = (1+R^i) - \frac{f_X}{X_0}(1+R^e). \tag{54}$$

The term $(1-\delta)E[S_1^i] - (1+r^i)S_0^i$ is the usual cost-of-carry calculation for the expected profit of keeping one unit of inventory. The new term, $S_0^i Y$, is the additional benefit of using commodities as collateral. In Case 2 and Case 4 of the equilibrium, the expression is similar but has an extra linear term in η.

Therefore, the theory strongly suggests that the forward-hedged interest-rate spread Y is a natural proxy for the attractiveness of importing commodities as collateral. While the comparative statics of Proposition 2 are calculated with respect to R^i, R^i and Y move one-for-one, fixing other parameters.

Since the CNY unsecured interest rates paid by small firms in China (R^i) and the USD unsecured interest rates paid by the financial investor (R^e) are unobservable to us, we use interbank rates as proxies. The two interbank rates are CNY Shibor (Shanghai Interbank Offered Rate) and USD Libor (London Interbank Offered Rate). 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 3). With these proxies, our empirical measure is

$$\hat{Y} = (1+Shibor) - \frac{f_X}{X_0}(1+Libor). \tag{55}$$

We calculate $\hat{Y}$ using three-month Libor, three-month Shibor, the official spot USDCNY exchange rate, and the three-month nondeliverable forward (NDF) USDCNY exchange rate.

The forward-hedged interest rate spread $\hat{Y}$ can also be viewed as the deviations from the covered interest-rate parity (CIP) in the USDCNY exchange rate, calculated using unsecured interbank rates.

Some readers may worry that Shibor significantly underestimates the true funding costs of small firms in China, and may suggest that we should use interest rates paid by "high-yield" Chinese borrowers that are much riskier than banks. This alternative route is very difficult because reliable high-yield data in China with reasonable sample length cannot be obtained.[17] Moreover, we argue that even if such data were available, one could not use it directly without further decomposing the credit spread (high-yield interest rate minus Shibor) into the expected default loss and the credit risk premium. This is because investors should rationally deduct the expected default loss from the high-yield interest rate, and judge the attractiveness of making the loan based on the trade-off between the credit risk premium and the risk of default. Credit risk premium, default risk, and expected default loss are even more difficult to measure in China than the high-yield interest rate itself. This concern is almost

[17] For instance, the Wenzhou Private Finance Index only started in late 2012.

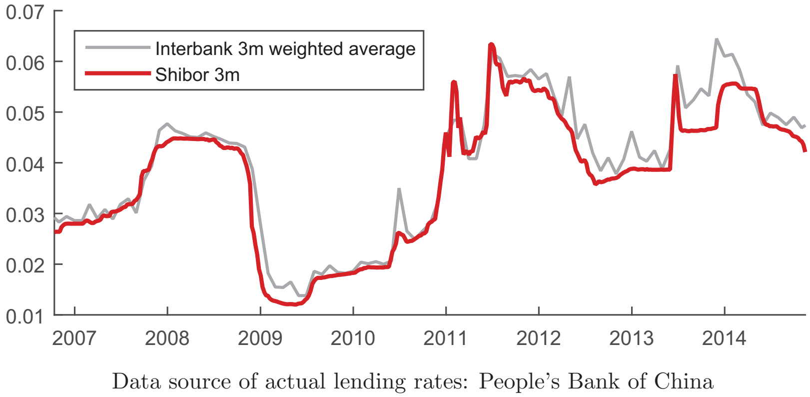


Figure 3
Shibor (weekly) versus quantity-weighted average lending rate (monthly)

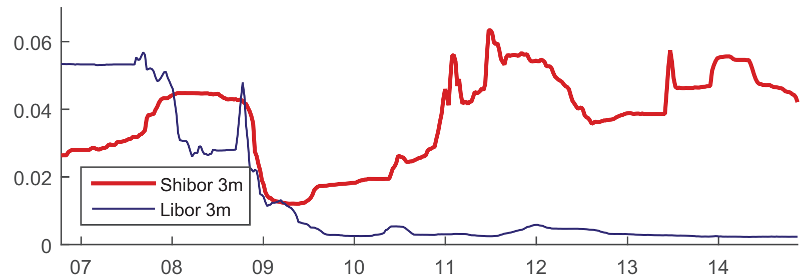
absent for Shibor because Shibor involves very low default risk.[18] In any case, what is important for us is that $\hat{Y}$ sufficiently captures the time variation, not necessarily the level, of investors' demand for commodities as collateral. Any noise in this measure would make it more difficult for us to find significant results in the data.

Our sample is weekly from October 13, 2006, to November 14, 2014, with 423 observations. While this sample is relatively short, it is precisely during this period that commodities are increasingly used as collateral for financing. Figure 4 plots our main proxy for the collateral demand of commodities, $\hat{Y}$, in Panel (a), as well as its components, in Panels (b) and (c). Overall, $\hat{Y}$ is stationary and mean-reverting, reaching local peaks in early 2008, mid-2011, and early 2014. Most of the time $\hat{Y} > 0$, implying a violation of the CIP in that CNY in the forward FX market is priced "too high" relative to the spot exchange rate.[19] The sole exception is a short period in late 2008 and early 2009, the depth of the crisis, when $\hat{Y}$ dropped to its minimum. Because of capital control, this deviation from the CIP cannot be eliminated by the usual arbitrage trades, which involve buying CNY in the spot market and selling CNY

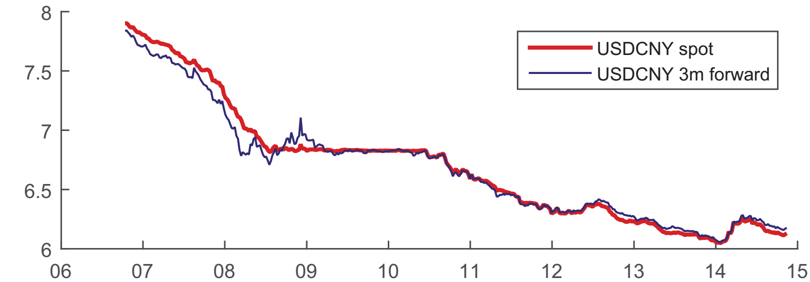
18 Furthermore, if lending at Shibor does happen in equilibrium, one may also view the expected profit of lending at Shibor (with very low default risk) as the investor's "certainty equivalent" of making high-expected-return, high-risk loans. This is because once the financial investor borrows CNY collateralized by commodities, he is free to lend the proceeds to banks at Shibor with very low default risk or to lend to firms with higher expected return but also higher risk. In equilibrium, the investor should be indifferent among all these options. If lending at Shibor does not happen in equilibrium because of too low an expected return, then the Shibor-based proxy $\hat{Y}$ is a lower bound, in terms of investor's utility function, on how attractive it is to import commodities as collateral.

19 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 a larger magnitude at 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).

(a) FX-hedged interest rate spread $\hat{Y}$



(b) Libor and Shibor



(c) USDCNY spot and forward exchange rates

Figure 4
Proxy for collateral demand of commodities, $\hat{Y}$, and its components

in the forward market, both physically delivered. The higher the deviation, the stronger the incentive to gain access to CNY investments by circumventing capital control, such as by importing commodities.[20]

[20] There are other ways to circumvent capital control. For example, Desai, Foley, and Hines (2006) report that U.S. multinational firms circumvent capital control by reducing reported foreign profitability and increasing dividends

Panel (b) of Figure 4 plots the time-series behaviors of Libor and Shibor. While Libor and Shibor are comparable before 2009, Shibor raises substantially above Libor after 2009. Panel (c) shows that CNY has been slowly and steadily appreciating against USD over the sample period.

4.2 Commodity prices and inventories

The commodities used to test the theoretical predictions are selected by two criteria. First, the commodities should have active futures or forward markets in China and in developed countries (e.g., the United States, the United Kingdom, Japan). Having a forward or futures market is important for calculating the convenience yield. Second, data for commodity prices and inventories should go back to at least the start of 2009, when Shibor started to increase substantially above Libor.

Applying these two criteria, we end up with eight commodities: copper, zinc, aluminum, 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 stronger 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 sources. With few exceptions, we take the prices of the first and third futures contracts in both the Chinese market and the developed markets.[21,22] 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 2013), 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.

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repatriation. In recent years it also has been widely suspected that certain companies in China "over-invoice" exports as a way to bring capital into China. S. Rabinovitch, "China to crack down on faked export deals," *Financial Times*, May 6, 2013.

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

22 Commodities traded in China are in CNY. Commodities traded in developed markets are in USD. (Rubber prices are originally in Japanese Yen (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

	Price data source		Inventory data source	
Commodity	China	Developed market	China	Developed market
Copper	SHFE, first and third futures	LME, cash and three-month forward	SHFE	LME
Zinc	SHFE, first and third futures	LME, cash and three-month forward	SHFE	LME
Aluminum	SHFE, first and third futures	LME, cash and three-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

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.

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

Besides $\hat{Y}$, other variables used in the empirical analysis are defined as follows.

- γ_t denotes the local interest rate (Shibor or Libor).
- S_t denotes spot prices extrapolated from traded futures prices. We follow Pindyck (2001) in inferring these spot prices because spot prices are often unavailable (except cash prices for copper, zinc, and aluminum on the LME).
- y_t denotes the convenience yield in the Chinese market or developed markets, calculated as

$$y_t = \frac{\ln(F(t,T_1)) - \ln(F(t,T_2))}{T_2 - T_1} + \gamma_t, \tag{56}$$

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

$$\hat{I}_t = I_t - \frac{1}{52}\sum_{j=1}^{52} I_{t-j}. \tag{57}$$

  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 2013).

Table 2 reports the summary statistics of the main variables. Most variables are in percents. In particular, the standard deviation of the collateral demand proxy $\hat{Y}$ is 82 basis points (bps) per week, which we will later use to assess the economic importance of the collateral demand for commodities.

Table 2
Summary statistics

(a) Collateral demand proxy $\hat{Y}$ and its components

	$\hat{Y}$ (%)	Shibor (%)	Libor (%)	USDCNY spot spot	USDCNY forward
Mean	0.76	3.74	1.44	6.69	6.68
Std. dev.	0.82	1.31	1.84	0.5	0.46
Median	0.66	3.94	0.39	6.66	6.65

(b) Commodity spot prices S_t and convenience yields y_t

		China		Developed markets	
	all in %	$\Delta\log(S_t)$	y_t	$\Delta\log(S_t)$	y_t
Copper	Mean	−0.09	8.94	−0.02	1.79
	Std. dev.	3.53	12.55	4.23	3.75
	Median	−0.05	6.74	−0.03	0.2
Zinc	Mean	−0.17	−1.45	−0.12	−2.56
	Std. dev.	3.63	10.22	4.73	3.93
	Median	0.1	−1.78	−0.2	−3.21
Aluminum	Mean	−0.1	0.73	−0.06	−4.44
	Std. dev.	2.15	12.85	3.41	4.63
	Median	−0.11	−0.42	−0.2	−5.13
Gold	Mean	0.02	1.23	0.08	−0.38
	Std. dev.	2.82	12.15	2.46	1.03
	Median	0.1	1.34	0.34	−0.32
Soybean	Mean	0.07	11.68	0.13	8.59
	Std. dev.	3.22	16.71	4.26	25.26
	Median	−0.23	13.52	0.48	−1.34
Corn	Mean	0.15	−3.65	0.05	−3.26
	Std. dev.	2.16	12.48	5	20.15
	Median	0.06	−4.77	0.35	−9.25
Fuel oil	Mean	0.01	−12	0.08	−3.99
	Std. dev.	5.63	30.65	4.21	9.81
	Median	0.1	−12.8	0.12	−3.09
Rubber	Mean	−0.12	2.02	−0.02	0.67
	Std. dev.	4.12	21.41	5.98	33.38
	Median	0.24	−3.3	0.02	−4.68

5. Empirical Evidence

In this section, we test two empirical predictions of our theory: how the demand for commodities as collateral, proxied by $\hat{Y}$, affects (i) commodity prices and (ii) the relation between inventory and convenience yield. In the next section we will check the robustness of these tests to the inclusion of China's macroeconomic conditions.

5.1 Commodity prices

Proposition 2 predicts that a higher collateral demand increases commodity 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:

$$\Delta\ln(S_t)=a+b\Delta y_t+c\Delta\gamma_t+d\Delta\hat{Y}_t+\epsilon_t. \tag{58}$$

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 (2006) shows that a higher interest rate is associated with lower commodity prices.

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

$$\Delta \ln(S_{i,t}) = a_i + b\Delta y_{i,t} + c\Delta \gamma_{i,t} + d\Delta \hat{Y}_t + \epsilon_{i,t}. \tag{59}$$

Our theory predicts that the coefficient d on $\Delta \hat{Y}_t$ should be positive in both China and developed markets.

Lastly, we run a larger panel regression across all eight commodities:

$$\Delta \ln(S_{i,t}) = a_i + b\Delta y_{i,t} + c\Delta \gamma_{i,t} + d\Delta \hat{Y}_t + \vec{f} \cdot 1(Metal) \cdot [\Delta y_{i,t}, \Delta \gamma_{i,t}, \Delta \hat{Y}_t] + \epsilon_{i,t}, \tag{60}$$

where $1(Metal)$ is the indicator function on metals (taking the value of 1 if the commodity is a metal and 0 otherwise), and the full set of interactive terms $1(Metal) \cdot [\Delta y_{i,t}, \Delta \gamma_{i,t}, \Delta \hat{Y}_t]$ captures the effect of metals versus nonmetals. Of particular interest is the coefficient for $1(Metal) \cdot \Delta \hat{Y}_t$, which captures the extent to which metal prices are more responsive to changes in collateral demand than nonmetal prices. We expect the coefficient for $1(Metal) \cdot \hat{Y}_t$ to be nonnegative.

Table 3 reports the results in Panel (a) for China and Panel (b) for developed markets.

For the metal group, as predicted by the theory, the panel regression shows a significantly positive d, suggesting that a higher demand to import commodities as collateral to China is associated with higher commodity prices in China and globally. For example, in the panel regression, if $\hat{Y}$ increases by 82 bps over a week (one standard deviation of $\hat{Y}$), then metal prices overall increase by 2.92% (=0.82% × 3.564) in China and 3.96% (=0.82% × 4.828) in developed markets. These are large magnitudes. The eight commodity-by-commodity regressions on metals reveal a significantly positive d, with the sole exception of gold in developed markets. The economic magnitudes are similar. If $\hat{Y}$ increases by one standard deviation, 82 bps, the contemporaneous increases in metal prices range from 2.63% for aluminum in China to 5.27% for copper in developed markets.

For the nonmetal group, the panel regressions and most individual commodity regressions also show a significantly positive d, although the magnitudes are smaller than those in the metal group. On average, an increase in $\hat{Y}$ by one standard deviation (82 bps) corresponds to a higher nonmetal commodity price of 1.29% in China and 2.85% in developed markets. The formal test reported in column (11) indicates that the metal-nonmetal difference is positive and statistically significant in both China and developed markets, and this difference is larger in China. These patterns are intuitive, as nonmetals are bulkier and more difficult to store and ship than metals.

Table 3
Commodity spot prices

(a) China

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\Delta\hat{Y}_t$	3.564**	3.414**	3.926**	3.202**	3.414**	1.568**	1.103**	0.983**	1.564	2.965*	1.568**
	(5.42)	(5.41)	(7.01)	(3.97)	(3.91)	(3.02)	(2.95)	(3.18)	(1.73)	(2.58)	(3.22)
$\Delta y_{i,t}$	0.0898	−0.0640	0.0583	0.131**	0.139**	0.155**	0.194**	0.317**	0.152**	0.0929*	0.155**
	(1.92)	(−1.04)	(1.52)	(2.92)	(16.68)	(14.00)	(7.02)	(9.13)	(6.23)	(2.10)	(15.04)
$\Delta\gamma_t$	−0.370	1.095	−1.447*	0.126	−1.474**	−0.528	−0.175	−1.529*	−1.411*	0.864	−0.528
	(−0.49)	(1.24)	(−2.29)	(0.24)	(−3.13)	(−0.88)	(−0.32)	(−2.29)	(−2.20)	(0.71)	(−0.96)
$1(Metal)\cdot\Delta\hat{Y}_t$											1.997**
											(107.86)
Observations	1536	422	395	422	297	1688	422	422	422	422	3224
Adjusted R^2	0.101	0.065	0.065	0.208	0.402	0.324	0.338	0.477	0.468	0.071	0.245

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.

(b) Developed markets

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\Delta\hat{Y}_t$	4.828**	6.428**	3.982**	4.310**	2.502	3.471**	3.402*	4.101	3.151	2.718*	3.471**
	(4.71)	(3.46)	(4.21)	(4.44)	(1.43)	(3.54)	(2.28)	(1.84)	(1.68)	(2.18)	(3.56)
$\Delta y_{i,t}$	0.877**	0.799**	1.166**	0.926**	0.416**	0.133**	0.157**	0.179**	0.466**	0.115**	0.133**
	(5.15)	(5.76)	(8.12)	(5.54)	(15.73)	(7.74)	(5.40)	(8.84)	(12.59)	(5.44)	(8.35)
$\Delta\gamma_t$	1.700	2.210	1.252	1.887	−7.236	−2.995	−1.798	−2.551	0.119	−7.768**	−2.995
	(0.95)	(1.01)	(1.09)	(1.19)	(−1.39)	(−1.21)	(−1.96)	(−1.19)	(0.06)	(−4.65)	(−1.25)
$1(Metal)\cdot\Delta\hat{Y}_t$											1.358*
											(2.10)
Observations	1536	422	395	422	297	1688	422	422	422	422	3224
Adjusted R^2	0.158	0.158	0.162	0.231	0.060	0.218	0.255	0.165	0.198	0.302	0.196

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.

Panel (a) reports results for China, and Panel (b) reports results for developed markets. Columns (1) and (6) report results from the panel regressions (59) for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Column (11) reports the results from panel regression (60), also with double-clustered standard errors. Columns (2)-(5) and (7)-(10) report results from regression (58) for individual commodities, where standard errors are calculated using the Newey-West method with 52 lags. All constants in regressions are suppressed in outputs. In column (11), coefficients for all interactive terms involving 1(*Metal*) are suppressed except $1(Metal)\cdot\Delta\hat{Y}_t$.

5.2 The 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 yield of holding commodities because it increases the real option value of consuming a commodity anytime. In our model of commodity as collateral, however, the relation is the reverse. As shown in Proposition 2 and Corollary 1, an increase in collateral demand tends to simultaneously increase inventories and convenience yield in the importing country. Thus, complementary to the theory of storage, a higher collateral demand for a commodity should make the inventory–convenience yield relation less negative in China. The theory makes no prediction about the inventory–convenience yield relation in developed markets, so the test here is restricted to China.

To test the inventory–convenience yield relation in the presence of the collateral use of commodities, we first normalize each detrended inventory by its time-series standard deviation:

$$\tilde{I}_{i,t} = \frac{\hat{I}_{i,t}}{\sqrt{\mathrm{Var}(\hat{I}_{i,t})}}. \tag{61}$$

Because commodity inventories have different units and scales, normalization makes it easier to interpret the regression coefficient.

As before, we run separate panel regressions for the metal group and the nonmetal group:

$$y_{i,t} = a_i + b\tilde{I}_{i,t} + c\tilde{I}_{i,t}\hat{Y}_t + \epsilon_{i,t} = a_i + \tilde{I}_{i,t}(b + c\hat{Y}_t) + \epsilon_{i,t}. \tag{62}$$

We also run commodity-by-commodity regressions:

$$y_t = a + b\tilde{I}_t + c\tilde{I}_t\hat{Y}_t + \epsilon_t = a + \tilde{I}_t(b + c\hat{Y}_t) + \epsilon_t. \tag{63}$$

As in the previous test, we run an eight-commodity panel regression with the metal indicator $1(Metal)$:

$$y_{i,t} = a_i + \tilde{I}_{i,t}(b + c\hat{Y}_t) + \vec{f} \cdot 1(Metal) \cdot [\tilde{I}_{i,t}, \tilde{I}_{i,t}\hat{Y}_t] + \epsilon_{i,t}. \tag{64}$$

The specifications in regressions (62), (63), and (64) make clear that it is the relation between $y_{i,t}$ and $\tilde{I}_{i,t}$ that we are testing. 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 the benefit of importing commodities as collateral, the more positive (or the less negative) the inventory–convenience yield relation. The coefficient for $1(Metal) \cdot \tilde{I}_{i,t}\hat{Y}_t$ captures the metal-nonmetal differential effect of collateral demand on the inventory–convenience yield relation. We also expect the coefficient for $1(Metal) \cdot \tilde{I}_{i,t}\hat{Y}_t$ to be nonnegative since metals are more suitable collateral than nonmetals.

Table 4 reports the results of regressions (62) and (63). As predicted by the theory, the panel regression on the metal group in China shows a significantly positive coefficient c on $\hat{I}_{i,t}\hat{Y}_t$. It reveals that the collateral use of commodities makes the inventory–convenience yield relation less negative. In individual commodity regressions, the same result is observed for zinc and gold, although the coefficients for copper and aluminum are insignificant. By contrast, the coefficient c for the nonmetal group is insignificant, in both the panel regression and individual commodity regressions. In the pooled regression of column (11), the coefficient for $1(Metal)\cdot\hat{I}_{i,t}\hat{Y}_t$ has the expected sign, but marginal significance with a t-statistic of 1.61. Despite weaker statistical significance, the test results here are consistent with the previous test and the theoretical predictions.

5.3 A brief discussion of the commodity futures risk premium

The key driver of futures risk premium in our model is the theory of normal backwardation. As argued by Keynes (1923), Hirshleifer (1990), and Bessembinder (1992), hedgers need to offer risk premiums in order to solicit speculators to offset their trades. Therefore, the theory of normal backwardation predicts that speculators who take long positions in futures contracts should earn a positive risk premium on average.

Empirically, however, tests of the theory of normal backwardation have yielded mixed results. For example, Rockwell (1967) and Dusak (1973) fail to find significant risk premiums in the futures contracts and thus reject the theory of normal backwardation. Using twenty-nine commodities futures, Kolb (1992) documents that less than one-third of commodities exhibit statistically significant positive average returns. On the other hand, Chang (1985) and Bessembinder (1992) find evidence supporting the theory of normal backwardation. In a review article by Rouwenhorst and Tang (2012), the authors retest the theory of normal backwardation using three different test methodologies in a recent sample of futures data. None of the tests find significant evidence that supports the theory of normal backwardation. The authors conclude that "the empirical support for the theory of normal backwardation is weak" (p. 456).

The weak empirical support for the theory of normal backwardation implies that any prediction from our model regarding the futures risk premium is likely weak at best. In particular, in our setting, the theory of normal backwardation predicts that futures risk premium should respond to R^i in the same way inventory does; that is, if the demand for collateral commodities goes up in week t, the futures risk premium realized in week $t+1$ should go up in China and go down in developed markets. But a test of this prediction is essentially a joint test of the theory of normal backwardation and our theory of commodity as collateral. In the data, we find no evidence of this joint prediction, that is, the collateral demand in week t cannot predict the futures risk premium realized in week $t+1$. Given the weak empirical support for the theory of

Table 4
Relation between inventory and convenience yield

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\tilde{I}_{i,t}\hat{Y}_t$	3.125*	7.638	4.007**	1.666	15.47**	0.370	−0.808	0.695	−1.317	4.716	0.370
	(2.14)	(1.37)	(3.19)	(0.74)	(8.30)	(0.36)	(−0.30)	(0.33)	(−0.61)	(1.15)	(0.38)
$\tilde{I}_{i,t}$	−0.0786**	−0.127*	−0.0858**	−0.0876**	−0.0904**	−0.0379	0.0112	−0.00867	−0.0389*	−0.135**	−0.0379
	(−4.57)	(−2.31)	(−6.89)	(−3.46)	(−7.48)	(−1.31)	(0.45)	(−0.35)	(−2.11)	(−2.85)	(−1.41)
$1(Metal)\cdot\tilde{I}_{i,t}\hat{Y}_t$											2.755
											(1.61)
Observations	1488	423	344	423	298	1640	423	423	423	371	3128
Adjusted R^2	0.315	0.293	0.342	0.323	0.181	0.166	−0.003	−0.002	0.023	0.206	0.200

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.
This table only reports results for China, as the theory does not make predictions for developed markets. Columns (1) and (6) report results from the panel regressions (62) for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Column (11) reports the results from panel regression (64), also with double-clustered standard errors. Columns (2)–(5) and (7)–(10) report results from regression (63) for individual commodities, where standard errors are calculated using the Newey-West method with 52 lags. All constants in regressions are suppressed in outputs. In column (11), coefficients for all interactive terms involving $1(Metal)$ are suppressed except $1(Metal)\cdot\tilde{I}_{i,t}\hat{Y}_t$.

normal backwardation, the lack of empirical evidence on risk premium in our setting is not that surprising and does not go against our theory of collateral. Indeed, we show that our theoretical predictions regarding commodity prices and the inventory–convenience yield relation, which do not rely on the theory of normal backwardation, are supported in the data.

6. Robustness to China's Macroeconomic Conditions

One may be concerned that the evidence shown in the previous section is partly driven by macroeconomic fundamentals, not frictions like capital control. In this section, we show that our empirical results are robust to the inclusion of China's macroeconomic conditions as control variables. Because China is the leading consumer and importer of commodities, China's macroeconomic fundamentals have large impacts on global commodities markets and hence are the most relevant controls for our purpose.

We use six indicators for China's macroeconomic conditions: Purchasing Managers Index (PMI), industry value added, electricity generation, rail freight volume, money supply, and Consumer Price Index (CPI), all obtained from the National Bureau of Statistics of China. All raw variables are at monthly frequency and converted to year-on-year growth. The sample is monthly from October 2006 to October 2014. Since these variables cover closely related aspects of China's economy, they are often correlated with one another. To make interpretation easier, we will include the six principal components (PCs) of the six indicators, instead of the raw data, in the regressions as control variables. The information content of the PCs is of course identical to the information in the raw indicators. The first three PCs of the six macroeconomic indicators explain 66.2%, 17.7%, and 7.7%, totaling 91.5%, of all time-series variations in the six indicators.

Moreover, since the macroeconomic data are available monthly but all other data are weekly, we construct weekly macroeconomic indicators by assuming that the year-on-year growth of each variable in each week is equal to that of the relevant month. Note that this assumption biases toward finding more significance on the macroeconomic indicators because macroeconomic data for each month are usually released after month end; hence, it is a conservative model specification for our purposes.

We run the same weekly regressions as in the previous section, but controlling for the PCs of the macroeconomic indicators. First, the following panel regressions are run separately on the metal group and nonmetal group:

$$\Delta \ln(S_{i,t}) = a_i + b\Delta y_{i,t} + c\Delta\gamma_{i,t} + d\Delta\hat{Y}_t + \vec{f}\cdot M\vec{P}C_t + \epsilon_{i,t}, \tag{65}$$

where $M\vec{P}C_t$ is the vector of the six macroeconomic PCs and $\vec{f}$ is a vector of six constants. The individual commodity regressions have the same form. We run these regressions in China and in developed markets, both controlling for $M\vec{P}C$. Lastly, we run an eight-commodity panel regression with a full set of interactive terms of the form $1(Metal)\cdot[\Delta y_{i,t}, \Delta\gamma_{i,t}, \Delta\hat{Y}_t, M\vec{P}C_t]$. As before, we expect d to be positive and the coefficient for $1(Metal)\cdot\Delta\hat{Y}_t$ to be nonnegative.

Second, we run the panel regressions on the relation between inventory and convenience yield:

$$y_{i,t} = a_i + b\tilde{I}_{i,t} + c\tilde{I}_{i,t}\hat{Y}_t + \vec{f}\cdot M\vec{P}C_t + \vec{g}\cdot\left(M\vec{P}C_t\cdot\tilde{I}_{i,t}\right) + \epsilon_{i,t}, \tag{66}$$

where we control both the macroeconomic PCs themselves and their interactions with inventory. This way, we allow the macroeconomic PCs to affect both the level of convenience yield and the inventory–convenience yield relation. The individual commodity regressions have the same form. Also as before, we run an eight-commodity panel regression with a full set of interactive terms of the form $1(Metal)\cdot[\tilde{I}_{i,t}, \tilde{I}_{i,t}\hat{Y}_t, M\vec{P}C_t, M\vec{P}C_t\cdot\tilde{I}_{i,t}]$. As before, we expect c to be positive and the coefficient for $1(Metal)\cdot\tilde{I}_{i,t}\hat{Y}_t$ to be nonnegative. The inventory–convenience yield regression is run only in China because, again, the theory makes no prediction about the inventory–convenience yield relation in developed markets.

The results from regression (65) are reported in Table 5, for prices in China, and Table 6, for prices in developed markets. Comparing Tables 5 and 6 with Table 3, we see that the coefficients in front of $\Delta\hat{Y}_t$ are robust to the inclusion of China's macroeconomic conditions. They remain significant and have almost identical magnitude. Controlling for macroeconomic conditions in China, a one-standard-deviation increase of $\hat{Y}_t$ corresponds to an increase of metal prices by 2.85% (=0.82% × 3.481) in China and 3.86% (=0.82% × 4.702) in developed markets. For copper in developed markets, the price increase is as high as 5.11% (=0.82% × 6.236) given the same increase in $\hat{Y}_t$. And as in the regression without macroeconomic control variables, the coefficient d for nonmetal commodities is also mostly significant but smaller in magnitude than the metal group counterpart. As in Table 3, metals are more sensitive than nonmetals in both China and developed markets, with a stronger effect in China. Overall, this evidence suggests that China's collateral demand and fundamental demand operate separately in a nonoverlapping fashion in driving commodity prices.

Table 7 reports the result for regression (66). As before, the metal group panel regression produces a significantly positive coefficient in front of $\tilde{I}_{i,t}\hat{Y}_t$, but the nonmetal group panel regression does not. Comparing Table 7 with Table 4, we see that the coefficient for $\tilde{I}_{i,t}\hat{Y}_t$ in the metals panel regression roughly doubles once macroeconomic controls are included. In individual commodity regressions, zinc and gold have significant coefficients in front of $\tilde{I}_{i,t}\hat{Y}_t$, just like in Table 4, and the magnitudes are marginally larger than those in Table 4. Moreover, once macroeconomic conditions are controlled for, the metal-nonmetal difference in column (11) becomes statistically significant. Overall, the effect of collateral demand on the inventory–convenience yield

Table 5
Collateral demand and commodity prices in China, controlling for China's macroeconomic conditions

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\Delta\hat{Y}_t$	3.481**	3.217**	3.891**	3.172**	3.352**	1.433**	0.988**	0.936**	1.356	2.804*	1.433**
	(5.74)	(5.09)	(6.23)	(4.10)	(3.90)	(3.12)	(2.69)	(3.08)	(1.43)	(2.45)	(3.37)
$\Delta y_{i,t}$	0.0921*	−0.0582	0.0590	0.137**	0.140**	0.153**	0.192**	0.311**	0.151**	0.0914*	0.153**
	(2.02)	(−0.91)	(1.52)	(2.93)	(17.49)	(15.27)	(6.80)	(8.98)	(6.34)	(2.06)	(16.58)
$\Delta\gamma_t$	−0.609	0.563	−1.345	−0.210	−1.696**	−1.185*	−0.688	−1.793**	−2.275*	−0.137	−1.185*
	(−0.95)	(0.70)	(−1.87)	(−0.73)	(−4.21)	(−2.15)	(−0.85)	(−3.72)	(−2.12)	(−0.11)	(−2.32)
$MPC_{1,t}$	0.0154	0.0244	−0.000166	0.0150	0.0273**	0.0334**	0.0243**	0.0151**	0.0413	0.0517**	0.0334**
	(1.48)	(1.31)	(−0.02)	(1.51)	(3.24)	(4.16)	(4.39)	(3.22)	(1.84)	(3.52)	(4.45)
$MPC_{2,t}$	0.0634**	0.0851**	0.101**	0.0466**	−0.0115	0.0275	−0.00135	0.00894	0.0382	0.0617*	0.0275
	(2.70)	(3.22)	(7.00)	(3.27)	(−1.12)	(1.61)	(−0.10)	(0.89)	(0.94)	(2.33)	(1.70)
$MPC_{3,t}$	0.0186	0.0191	0.0305	0.0141	0.00277	0.00886	−0.00648	−0.00500	−0.00874	0.0646	0.00886
	(0.96)	(0.68)	(1.00)	(1.07)	(0.14)	(0.40)	(−0.24)	(−0.44)	(−0.27)	(1.68)	(0.42)
$MPC_{4,t}$	0.00741	0.0512	−0.0122	−0.00667	0.0274	0.0376	0.0201	0.00788	0.0697	0.0444	0.0376*
	(0.32)	(1.45)	(−0.37)	(−0.40)	(1.43)	(1.93)	(0.66)	(0.78)	(1.74)	(1.27)	(2.01)
$MPC_{5,t}$	0.0537	0.134	−0.0562	0.0567	0.188**	0.151**	0.133**	0.0488	0.252*	0.174	0.151**
	(0.82)	(1.75)	(−0.79)	(1.54)	(3.28)	(3.26)	(3.20)	(1.91)	(2.34)	(1.77)	(3.45)
$MPC_{6,t}$	−0.0152	−0.0977	0.0901	0.0683	−0.0297	−0.0386	−0.122	−0.0112	−0.0500	0.0430	−0.0386
	(−0.14)	(−0.69)	(0.82)	(1.17)	(−0.19)	(−0.58)	(−0.97)	(−0.13)	(−0.49)	(0.26)	(−0.59)
$1(Metal)\cdot\Delta\hat{Y}_t$											2.047**
											(7.05)
Observations	1528	420	393	420	295	1680	420	420	420	420	3208
Adjusted R^2	0.122	0.094	0.087	0.229	0.413	0.341	0.346	0.469	0.484	0.105	0.263

t-statistics in parentheses.
* $p < 0.05$, ** $p < 0.01$.
Columns (1) and (6) report results from panel regression (65) for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Column (11) reports the results from the eight-commodity panel regression with the metal indicator $1(Metal)$, also with double-clustered standard errors. Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 52 lags. All constants in regressions are suppressed in outputs. In column (11), coefficients for all interactive terms involving $1(Metal)$ are suppressed except $1(Metal)\cdot\Delta\hat{Y}_t$.

Table 6
Collateral demand and commodity prices in developed markets, controlling for China's macroeconomic conditions

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\Delta\hat{Y}_t$	4.702**	6.236**	3.878**	4.184**	2.288	3.303**	3.334*	4.000	2.970	2.405	3.303**
	(4.88)	(3.60)	(4.32)	(4.74)	(1.35)	(3.47)	(2.18)	(1.81)	(1.63)	(1.86)	(3.50)
$\Delta y_{i,t}$	0.902**	0.767**	1.178**	0.946**	0.409**	0.132**	0.157**	0.178**	0.457**	0.114**	0.132**
	(5.54)	(4.87)	(8.29)	(5.85)	(12.88)	(7.71)	(5.24)	(8.42)	(14.13)	(5.44)	(8.32)
$\Delta\gamma_t$	1.484	2.090	1.195	1.405	−12.86	−3.286	−1.621	−2.502	−0.263	−8.605**	−3.286
	(0.89)	(1.08)	(1.00)	(1.20)	(−1.70)	(−1.33)	(−1.24)	(−1.45)	(−0.21)	(−3.67)	(−1.39)
$MPC_{1,t}$	0.0176	0.0246	−0.00268	0.0316*	0.0271**	0.0338*	0.00744	0.0174	0.0403	0.0683*	0.0338*
	(1.45)	(1.22)	(−0.23)	(2.04)	(2.84)	(1.97)	(0.71)	(1.60)	(1.43)	(2.58)	(2.07)
$MPC_{2,t}$	0.0666*	0.0835**	0.108**	0.0578**	−0.0240*	0.0285	0.000436	0.0104	0.0283	0.0658*	0.0285
	(2.55)	(3.31)	(8.25)	(4.06)	(−1.99)	(1.27)	(0.02)	(0.45)	(0.80)	(2.06)	(1.31)
$MPC_{3,t}$	0.0270	0.0506	0.0327	0.0168	0.00518	0.0226	0.00704	−0.0101	0.0104	0.0635	0.0226
	(0.97)	(1.67)	(0.90)	(0.67)	(0.24)	(0.80)	(0.20)	(−0.26)	(0.24)	(1.34)	(0.82)
$MPC_{4,t}$	0.00457	0.0305	0.00845	−0.0233	0.0121	0.0119	0.0228	0.0133	0.000191	0.0421	0.0119
	(0.17)	(1.04)	(0.22)	(−0.90)	(0.47)	(0.34)	(0.50)	(0.30)	(0.01)	(1.25)	(0.35)
$MPC_{5,t}$	0.0768	0.133	0.00348	0.106*	0.199**	0.181**	0.145**	0.209*	0.243**	0.108	0.181**
	(1.16)	(1.72)	(0.05)	(2.28)	(2.90)	(3.13)	(3.22)	(2.38)	(2.64)	(1.00)	(3.20)
$MPC_{6,t}$	−0.00245	−0.0509	−0.0227	0.118	−0.0279	0.0469	0.0411	0.117	0.0759	−0.0306	0.0469
	(−0.02)	(−0.37)	(−0.15)	(0.98)	(−0.20)	(0.48)	(0.28)	(0.75)	(0.65)	(−0.23)	(0.48)
$1(Metal)\cdot\Delta\hat{Y}_t$											1.399*
											(1.99)
Observations	1528	420	393	420	295	1680	420	420	420	420	3208
Adjusted R^2	0.174	0.175	0.173	0.253	0.058	0.230	0.014	0.004	0.028	0.089	0.210

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.
Columns (1) and (6) report results from panel regressions (65) for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Column (11) reports the results from the eight-commodity panel regression with the metal indicator 1(*Metal*), also with double-clustered standard errors. Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 52 lags. All constants in regressions are suppressed in outputs. In column (11), coefficients for all interactive terms involving 1(*Metal*) are suppressed except $1(Metal)\cdot\Delta\hat{Y}_t$.

Table 7
Inventory–convenience yield relation in China, controlling for China's macroeconomic conditions

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber	(11) All
$\tilde{I}_{i,t}\hat{Y}_t$	6.445**	4.313	5.405*	2.436	18.93**	0.606	−2.666	−0.647	−3.408	−4.414	0.606
	(3.32)	(1.47)	(2.02)	(1.22)	(5.18)	(0.33)	(−0.82)	(−0.33)	(−0.56)	(−1.32)	(0.36)
$\tilde{I}_{i,t}$	−0.103**	−0.100**	−0.0949*	−0.0976**	−0.126**	−0.0220	0.0555*	−0.0216	−0.0147	−0.00918	−0.0220
	(−12.08)	(−3.26)	(−2.36)	(−4.89)	(−4.53)	(−0.69)	(2.36)	(−0.81)	(−0.19)	(−0.20)	(−0.74)
$MPC_{1,t}$	−0.192	−0.456**	−0.380*	0.221	0.00996	−0.189	−0.543**	−0.192	0.415*	−0.724**	−0.189
	(−0.96)	(−3.22)	(−2.58)	(1.62)	(0.08)	(−0.84)	(−2.98)	(−1.74)	(2.40)	(−3.95)	(−0.91)
$MPC_{2,t}$	−0.0203	−0.101	−0.0115	0.371**	−0.0891	−0.751*	−1.033**	0.314	−0.788	−1.648**	−0.751*
	(−0.15)	(−0.71)	(−0.08)	(2.62)	(−0.93)	(−2.31)	(−3.50)	(1.33)	(−1.41)	(−4.06)	(−2.49)
$MPC_{3,t}$	0.0190	0.167	−0.0956	0.155	−0.0196	0.0594	−1.034	−0.542*	−0.552	1.161	0.0594
	(0.24)	(0.75)	(−0.38)	(0.76)	(−0.15)	(0.15)	(−1.80)	(−2.28)	(−1.11)	(1.67)	(0.16)
$MPC_{4,t}$	0.251*	0.457*	0.413	0.387**	−0.0183	0.0493	−0.356	−0.874	0.537	−0.593	0.0493
	(2.30)	(2.56)	(1.36)	(2.90)	(−0.17)	(0.16)	(−0.53)	(−1.66)	(0.44)	(−1.11)	(0.17)
$MPC_{5,t}$	−0.742*	−1.082*	0.236	−1.284**	−0.149	−0.165	0.799	−1.868**	2.062**	−1.254	−0.165
	(−2.47)	(−2.09)	(0.25)	(−2.78)	(−0.35)	(−0.19)	(1.57)	(−3.69)	(3.25)	(−1.38)	(−0.20)
$MPC_{6,t}$	−1.706	0.683	0.00590	−3.805**	−0.0672	2.221	6.136**	−0.231	3.783	−4.317	2.221
	(−1.04)	(1.05)	(0.00)	(−3.41)	(−0.04)	(1.43)	(3.75)	(−0.15)	(1.95)	(−1.86)	(1.55)
$\tilde{I}_{i,t} \cdot MPC_{1,t}$	−0.0341	0.325*	0.258**	−0.234*	−0.136	0.0458	0.436**	0.143	−0.288	0.362**	0.0458
	(−0.24)	(2.16)	(3.19)	(−2.05)	(−1.32)	(0.33)	(2.70)	(1.52)	(−1.48)	(4.91)	(0.35)
$\tilde{I}_{i,t} \cdot MPC_{2,t}$	0.534*	0.316	0.0679	0.0272	0.233	0.465*	0.200	0.486*	0.000765	0.714	0.465*
	(2.33)	(1.15)	(0.44)	(0.13)	(1.83)	(2.11)	(0.63)	(2.35)	(0.00)	(1.43)	(2.28)
$\tilde{I}_{i,t} \cdot MPC_{3,t}$	−0.0783	−0.360	0.257	−0.475	0.0655	−0.312**	−0.0355	0.163	−0.316	−0.892	−0.312**
	(−0.58)	(−1.95)	(1.53)	(−1.81)	(0.77)	(−2.82)	(−0.07)	(0.60)	(−0.47)	(−1.72)	(−2.85)
$\tilde{I}_{i,t} \cdot MPC_{4,t}$	−0.0593	−0.641*	0.140	−0.233	0.133	−0.196	0.290	−0.330	0.914	0.793	−0.196
	(−0.58)	(−1.99)	(0.36)	(−0.52)	(0.64)	(−0.68)	(0.53)	(−0.86)	(1.46)	(1.15)	(−0.73)
$\tilde{I}_{i,t} \cdot MPC_{5,t}$	−0.971*	−0.0827	0.299	−0.291	−0.815	0.335	−0.340	0.569	1.073	1.121	0.335
	(−2.34)	(−0.18)	(0.48)	(−0.48)	(−1.52)	(0.86)	(−0.51)	(0.81)	(1.34)	(1.28)	(0.92)
$\tilde{I}_{i,t} \cdot MPC_{6,t}$	−0.672	−1.420	0.402	0.963	−0.553	1.385	0.779	2.581**	2.557	−0.740	1.385
	(−0.76)	(−1.30)	(0.34)	(1.01)	(−0.52)	(1.43)	(0.26)	(2.94)	(1.18)	(−0.29)	(1.54)
$1(Metal) \cdot \tilde{I}_{i,t}\hat{Y}_t$											5.840*
											(2.29)
Observations	1480	421	342	421	296	1632	421	421	421	369	3112
Adjusted R^2	0.398	0.541	0.465	0.532	0.172	0.207	0.283	0.393	0.096	0.456	0.249

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.
Columns (1) and (6) report results from panel regression (66) for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Column (11) reports the results from the eight-commodity panel regression with the metal indicator 1(*Metal*), also with double-clustered standard errors. Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 52 lags. All constants in regressions are suppressed in outputs. In column (11), coefficients for all interactive terms involving 1(*Metal*) are suppressed except $1(Metal) \cdot \tilde{I}_{i,t}\hat{Y}_t$.

relation is robust to the inclusion of macroeconomic indicators. (We rerun monthly regressions in Table 7 and results are similar.)

7. 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 earn higher expected returns. A simple model shows that, all else equal, higher (lower) collateral demand increases (decreases) the concurrent commodity spot prices globally; it also increases (decreases) inventory and convenience yield simultaneously in the importing country.

We test the model predictions in China and developed markets, using price and inventory data of four metals and four nonmetal commodities, from October 13, 2006, to November 14, 2014. Our empirical proxy for collateral demand of commodities is the forward-hedged interest-rate spread, which is essentially the deviation from the covered interest-rate parity. Because of capital control in China, this proxy in our sample period is almost always positive and mean-reverting.

Empirical tests strongly support our theory. Higher collateral demand for commodities is associated with (i) higher commodity prices globally, and (ii) a less negative inventory–convenience yield relation in China. The economic magnitude is also large. For example, a one-standard-deviation increase in collateral demand increases metal prices by about 3% in China and by about 4% in developed markets. The same change in collateral demand increases nonmetal commodity prices by about 1.3% in China and 2.9% in developed markets. The estimates remain significant with roughly the same magnitude even after controlling for China's economic fundamentals.

Our contribution to the commodities literature can be summarized along the three important dimensions highlighted by Cheng and Xiong (2014): storage, risk sharing, and information discovery. In terms of 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. With regard to risk-sharing, we find evidence of intermarket spillover: commodity prices are strongly affected by CIP violation in the foreign exchange market. And, for 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 the 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 A1
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 $j \in \{e,i\}$
δ	Storage cost of commodity
h	Shipping cost of commodity
G_t^e	Commodity production of the exporting country at time t
k_t, l	If D_t^i units of commodity are used, the fundamental consumer's profit per unit of commodity is $k_t - S_t^i - l D_t^i$.
a_0, a_1	Commodity supply in the importing country is a_t in period t
γ_p^e, γ_s^e	Risk-aversion coefficients of commodity producer and financial speculator in the exporting country
γ_d^i, γ_c^i	Risk-aversion coefficients of fundamental commodity consumer and financial investor in the importing country
X_t, f_X	Spot and forward exchange rates between the two countries' currencies
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 in period 0, all imported
λ	Lagrange multiplier associated with constraint $I_0^e \geq 0$
η	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 in period 0
h_d^i, h_c^i	Positions of futures contracts of fundamental commodity consumer and financial investor in importing country in period 0
σ_S^j	Volatility of S_1^j for $j \in \{e,i\}$

Appendix B. Proof of Proposition 1 and Proposition 2

In this appendix we show detailed steps in solving the equilibrium characterized in Proposition 1 and the comparative statics in Proposition 2. The parametric conditions (Technical Conditions 1–3) for this equilibrium are summarized in Appendix 7.

Define $u_X = E[X_1]$ and $\sigma_{S_1^e,X_1} = \text{Cov}[S_1^e, X_1]$. Recall $(\sigma_S^e)^2 = \text{Var}[S_1^e]$.

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

$$m = \frac{1}{(\sigma_S^i)^2}\left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right), \tag{A1}$$

$$n = \frac{1}{(\sigma_S^e)^2}\left(\frac{\gamma_s^e + \gamma_p^e}{\gamma_s^e \gamma_p^e}\right), \tag{A2}$$

$$q = \mu_k + (1-\delta)k_0 - 2l((1-\delta)a_0 + a_1) - 2l\left((1-\delta)G_0^e + G_1^e\right), \tag{A3}$$

$$b = \frac{q - \sigma_{S_1^e,X_1}}{u_X}, \tag{A4}$$

$$v = \frac{1-\delta}{2l}, \tag{A5}$$

$$w = \frac{\frac{f_X}{X_0}(1+R^e)-(R^i-r^i)}{1-\delta}, \tag{A6}$$

$$z = \frac{1+r^e}{1-\delta}, \tag{A7}$$

$$o = \frac{1+R^e}{1-\delta}\frac{f_X}{X_0}. \tag{A8}$$

Note that as R^i increases, w decreases, but none of the other variables are directly affected by R^i. Only b and n may be indirectly affected by R^i through the endogenous constants $\sigma_{S_1^e,X_1}$ and $(\sigma_S^e)^2$.

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:

$$G_0^e - I_0^e = \left[\frac{k_0 - S_0^i}{2l} - a_0\right] + \left(\frac{\gamma_d^i + \gamma_c^i}{\gamma_d^i \gamma_c^i}\right)\frac{E\left[S_1^i - F^i\right]}{(1-\delta)\left(\sigma_S^i\right)^2}, \tag{A9}$$

$$I_0^e(1-\delta)+G_1^e = \frac{\gamma_s^e+\gamma_p^e}{\gamma_s^e\gamma_p^e}\frac{E\left[S_1^e - F^e\right]}{\left(\sigma_S^e\right)^2}, \tag{A10}$$

$$I_0^e(1-\delta)+G_1^e = \frac{k_1 - S_1^i}{2l} - \left(a_1 + \left(\frac{\gamma_d^i+\gamma_c^i}{\gamma_d^i\gamma_c^i}\right)\frac{E\left[S_1^i - F^i\right]}{\left(\sigma_S^i\right)^2}\right), \tag{A11}$$

$$S_1^i = (S_1^e + h)X_1, \tag{A12}$$

$$S_0^i = (S_0^e + h)X_0 - 2l\eta. \tag{A13}$$

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 Equations (A9) and (A11) we get

$$\left(\sigma_S^i\right)^2 = (\sigma_k)^2, \tag{A14}$$

$$\begin{aligned} E\left[S_1^i\right] &= \mu_k + (1-\delta)k_0 - 2l((1-\delta)a_0 + a_1) - 2l\left((1-\delta)G_0^e + G_1^e\right) - (1-\delta)S_0^i \\ &= q - (1-\delta)S_0^i. \end{aligned} \tag{A15}$$

We also get

$$E\left[S_1^e\right] = \frac{E\left[S_1^i\right] - \sigma_{S_1^e,X_1}}{u_X} - h, \tag{A16}$$

$$\left(\sigma_S^e\right)^2 = \text{Var}\left[\frac{S_1^i}{X_1}\right]. \tag{A17}$$

The futures prices are given by

$$F^e = \frac{S_0^e(1+r^e)-\lambda}{1-\delta} = \frac{\left(\frac{S_0^i+2l\eta}{X_0}-h\right)(1+r^e)-\lambda}{1-\delta} \tag{A18}$$

$$= \frac{z}{X_0}S_0^i - hz + \frac{2lz\eta}{X_0} - \frac{\lambda}{1-\delta}, \tag{A19}$$

$$F^i = \frac{\left(\frac{f_X}{X_0}(1+R^e)-(R^i-r^i)\right)}{1-\delta}S_0^i + \frac{f_X}{X_0}\frac{2l(1+R^e)}{1-\delta}\eta. \tag{A20}$$

Equations (A9) and (A10) can be rewritten as

$$G_0^e - I_0^e = \left[\frac{k_0-S_0^i}{2l}-a_0\right] + \frac{m}{(1-\delta)}E\left[S_1^i - F^i\right], \tag{A21}$$

$$I_0^e(1-\delta)+G_1^e = nE\left[S_1^e - F^e\right]. \tag{A22}$$

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

$$\begin{aligned}(1-\delta)G_0^e+G_1^e &= (1-\delta)\left[\frac{k_0-S_0^i}{2l}-a_0\right]+mE\left[S_1^i-F^i\right]+nE\left[S_1^e-F^e\right]\\ &= \frac{(1-\delta)(k_0-2a_0l)}{2l}-vS_0^i\\ &\quad +mq-(1-\delta+w)mS_0^i-2lmo\eta\\ &\quad +n(b-h+zh)-((1-\delta)/u_X+z/X_0)nS_0^i-2lnz\eta/X_0+\frac{n\lambda}{1-\delta}.\end{aligned} \tag{A23}$$

Thus,

$$S_0^i = \frac{\left[\begin{array}{c}\frac{(1-\delta)(k_0-2a_0l)}{2l}+mq+n(b-h+zh)-\left[G_0^e(1-\delta)+G_1^e\right]\\ +\frac{n}{1-\delta}\lambda-2l(om+zn/X_0)\eta\end{array}\right]}{v+(1-\delta+w)m+((1-\delta)/u_X+z/X_0)n}, \tag{A24}$$

$$S_0^e = \frac{S_0^i+2l\eta}{X_0}-h. \tag{A25}$$

By Equations (A9) and (A11), the period 1 prices are

$$S_1^i = E[S_1^i]+k_1-\mu_k = q-(1-\delta)S_0^i+k_1-\mu_k, \tag{A26}$$

$$S_1^e = \frac{S_1^i}{X_1}-h. \tag{A27}$$

By Equation (A10), the inventory in the exporting country is

$$I_0^e = \frac{1}{1-\delta}\left[n(b-h+zh)-((1-\delta)/u_X+z/X_0)nS_0^i-G_1^e-2nlz\eta/X_0+\frac{n\lambda}{1-\delta}\right]. \tag{A28}$$

Furthermore,

$$C_0^i = \frac{m}{1-\delta}\left[q-(1-\delta+w)S_0^i-2lo\eta\right]. \tag{A29}$$

The last step is to solve the two endogenous constants $\sigma_{S_1^e,X_1}$ and $(\sigma_S^e)^2$, since they depend on the equilibrium commodity prices. By definition, $\sigma_{S_1^e,X_1}$ is given by

$$\sigma_{S_1^e,X_1}=\mathrm{Cov}\left[\frac{S_1^i}{X_1}-h,X_1\right]=\mathrm{Cov}\left[\frac{k_1}{X_1},X_1\right]+(q-\mu_k-(1-\delta)S_0^i)\mathrm{Cov}\left[\frac{1}{X_1},X_1\right], \tag{A30}$$

where we have substituted in the equilibrium S_0^i. Similarly, $(\sigma_S^e)^2$ is given by

$$(\sigma_S^e)^2=\mathrm{Var}\left[\frac{q-(1-\delta)S_0^i+k_1-\mu_k}{X_1}\right]. \tag{A31}$$

Note that $\sigma_{S_1^e,X_1}$ and $(\sigma_S^e)^2$ are trivially read out from Equations (A30) and (A31) as long as S_0^i does not depend on b or n in equilibrium.

There are four cases. For the simplicity of exposition, we start with Case 4 and finish with Case 1.

Case 4 ($\lambda>0$ and $\eta>0$, that is, $I_0^e=0$ and $D_{0,f}^i=0$). In this case, the collateral demand drives up the price in the exporting country sufficiently and produces two effects. First, the commodity producer in the exporting country 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 $D_{0,f}^i=0$, which implies that $S_0^i=k_0-2a_0l$. Therefore, we have

$$S_0^i=\frac{\left[\begin{array}{c}\frac{(1-\delta)(k_0-2a_0l)}{2l}+mq+n(b-h+zh)-\left[G_0^e(1-\delta)+G_1^e\right]\\+\frac{n}{1-\delta}\lambda-2l(om+zn/X_0)\eta\end{array}\right]}{v+(1-\delta+w)m+((1-\delta)/u_X+z/X_0)n}=k_0-2a_0l, \tag{A32}$$

$$I_0^e=\frac{1}{1-\delta}\left[n(b-h+zh)-((1-\delta)/u_X+z/X_0)nS_0^i-G_1^e-2nlz\eta/X_0+\frac{n\lambda}{1-\delta}\right]=0. \tag{A33}$$

We can solve λ and η from the above two equations. Then, it is easy to further solve all other variables in the equilibrium.

In particular, from Equations (A32)–(A33), we get

$$(1-\delta+w)(k_0-2a_0l)+2lo\eta=q-m^{-1}G_0^e(1-\delta). \tag{A34}$$

Thus, the importing country's inventory is

$$C_0=\frac{m}{1-\delta}(q-(1-\delta+w)S_0^i-2lo\eta)=G_0^e,$$

which is invariant to R^i. The importing country's convenience yield is

$$y^i=-w+\frac{1+r^i}{1-\delta}-\frac{2lo\eta}{S_0^i}.$$

By Equation (A34),

$$wS_0^i+2lo\eta=q-m^{-1}G_0^e(1-\delta)-(1-\delta)(k_0-2a_0l),$$

which is also invariant to R^i. So y^i is invariant to R^i.

Lastly, since the right-hand side of Equation (A34) is invariant to R^i, the left-hand side must also be invariant to R^i. But as R^i increases, w decreases. So η must increase in R^i. By $S_0^i=(S_0^e+h)X_0-2l\eta$, we conclude that S_0^e is increasing in R^i.

Case 3 ($\lambda > 0$ and $\eta = 0$, that is, $I_0^e = 0$ and $D_{0,f}^i > 0$). In this case, collateral demand leads to a sufficiently high price and zero inventory in the exporting country. Since $I_0^e = 0$ and $\eta = 0$, combining Equations (45) and (49), one can get

$$S_0^i = \frac{\frac{(1-\delta)(k_0 - 2a_0 l)}{2l} - G_0^e(1-\delta) + mq}{v + (1-\delta+w)m}. \tag{A35}$$

Thus, combining Equations (45) and (A35), one can solve for λ. After getting S_0^i and λ, all other variables can be solved.

Equation (A35) implies that S_0^i increases in R^i, for w decreases in R^i. Given $S_0^i = (S_0^e + h)X_0$, S_0^e also increases in R^i. The convenience yield given by Equation (50) also increases in R^i by substituting in $\eta = 0$. Lastly, $(1-\delta+w)S_0^i$ increases in w, so C_0^i as in Equation (A29) increases in R^i.

Case 2 ($\lambda = 0$ and $\eta > 0$, that is, $I_0^e > 0$ and $D_{0,f}^i = 0$). In this case, collateral demand leads to zero import by fundamental consumers. Thus,

$$D_{0,f}^i = \frac{k_0 - 2a_0 l - S_0^i}{2l} = 0, \tag{A36}$$

or $S_0^i = k_0 - 2a_0 l$, as in Case 4.

Given $\lambda = 0$, from Equation (45) we can explicitly obtain η. After getting S_0^i and η, we can solve all other variables.

In this case, since S_0^i is invariant to R^i, the right-hand side of Equation (45) is also invariant to R^i. Moreover, $\sigma_{S_1^e, X_1}$ and $(\sigma_S^e)^2$, given by Equations (A30)–(A31), are both invariant to R^i; so are n and b. This means that the only terms on the right-hand side of Equation (45) that can vary with R^i are w and η. Thus, as R^i increases, η must increase to offset the effect of the decreasing w.

To calculate C_0^i, we rewrite Equation (45) as

$$m[(1-\delta+w)(k_0 - 2a_0 l) + 2lo\eta] = mq + n(b - h + zh) - [G_0^e(1-\delta) + G_1^e] - 2lzn\eta / X_0$$
$$- ((1-\delta)/u_X + z/X_0)n(k_0 - 2a_0 l),$$

whose right-hand side is decreasing in η and hence decreasing in R^i. Then Equation (A29) implies that C_0^i is increasing in R^i.

By the same reasoning, we infer that $w(k_0 - 2a_0 l) + 2lo\eta$ is decreasing in R^i, so

$$y^i = -w + \frac{1+r^i}{1-\delta} - \frac{2lo\eta}{S_0^i}$$

is increasing in R^i.

Case 1 ($\lambda = 0$ and $\eta = 0$, that is, $I_0^e > 0$ and $D_{0,f}^i > 0$). In this case, the demand for collateral commodity does not lead to a stockout in the exporting country or zero import by the fundamental consumer in the importing country. Since neither constraint is binding, the equilibrium prices and inventory are given by Equations (45)–(49) after substituting in $\lambda = \eta = 0$.

Since the expression of S_0^i contains both n and b, the constants $\sigma_{S_1^e, X_1}$ and $(\sigma_S^e)^2$ cannot be read out from Equations (A30) and (A31); instead, they must solve a fixed point. The only term on the right-hand side of Equation (A30) that contains $\sigma_{S_1^e, X_1}$ is S_0^i, and S_0^i is decreasing in $\sigma_{S_1^e, X_1}$ through its relation to the parameter b. Since $\mathrm{Cov}[1/X_1, X_1] < 0$, a larger $\sigma_{S_1^e, X_1}$ reduces S_0^i and reduces the right-hand side of Equation (A30). But the left-hand side is obviously increasing in $\sigma_{S_1^e, X_1}$. This implies a unique solution of $\sigma_{S_1^e, X_1}$ as an endogenous constant.

The only term on the right-hand side of Equation (A31) that contains $(\sigma_S^e)^2$ is S_0^i. Observe that Equation (A31) has at least one solution because, as $(\sigma_S^e)^2$ goes from 0 to infinity, the right-hand side of Equation (A31) always stays positive and finite. The expression of S_0^i contains $(\sigma_S^e)^2$ through n, and n shows up in S_0^i twice, once in the numerator and once in the denominator, both linearly. Thus, potentially, there can be multiple roots of Equation (A31). If multiple roots exist, we select one as follows. Recall that a unique solution exists in Cases 2 and 3. Starting from Case 1, as R^i increases sufficiently, the equilibrium will move to either Case 2 (fundamental consumer only uses domestic commodity) or Case 3 (stockout in exporting country). Then, moving back from Case 2 or Case 3 to Case 1 by reducing R^i, if multiple roots merge, we pick one that gives the continuity of equilibrium.

Explicit solutions and comparative statics can be obtained in the limit of $\gamma_s^e \to 0$, since in this case $n \to \infty$ and Equation (45) implies that

$$S_0^i = \frac{(q - \sigma_{S_1^e, X_1})/u_X - h + zh}{(1-\delta)/u_X + z/X_0}. \tag{A37}$$

The combination of Equations (A37) and (A30) leads to a unique solution $(S_0^i, \sigma_{S_1^e, X_1})$ that is invariant to R^i. And $(\sigma_S^e)^2$ is directly read out from Equation (A31). By Equation (A29), C_0^i is increasing in R^i since w is decreasing in R^i. And y^i defined in Equation (50) is obviously increasing in R^i.

B.1 Technical Conditions

B.1.1 Zero non-collateral inventory in the importing country

Proposition 1 is solved under the condition that the commodity producer in the importing country does not wish to keep inventory. This condition is equivalent to the convenience yield, y^i, given in Equation (50), being positive. Thus, in equilibrium, we need

$$\frac{(1+R^i) - (1+R^e)\frac{f_X}{X_0}}{1-\delta} > \frac{2lo\eta}{S_0^i}. \tag{A38}$$

Case 1 and Case 3. In these cases $\eta = 0$, so Equation (A38) reduces to $Y > 0$, where $Y = (1 + R^i) - \frac{f_X}{X_0}(1 + R^e)$ as in Equation (51).

Case 2. Combining $S_0^i = k_0 - 2a_0 l$, $\lambda = 0$, and Equation (45), we solve

$$\eta = \frac{mq + n(b - h + zh) - [G_0^e(1-\delta) + G_1^e] - S_0^i[(1-\delta+w)m + ((1-\delta)/u_X + z/X_0)n]}{2l(om + zn/X_0)}. \tag{A39}$$

As R^i increases by one unit, the left-hand side of Equation (A38) increases by $1/(1-\delta)$ units, but the right-hand side of Equation (A38) increases by

$$\frac{2lo}{S_0^i} \cdot \frac{S_0^i m/(1-\delta)}{2l(om + zn/X_0)} < \frac{1}{1-\delta}$$

units, where we have used the fact that $\partial w/\partial R^i = -1/(1-\delta)$. Thus, to ensure that Equation (A38) holds for all $\eta > 0$, it suffices to ensure that Equation (A38) holds for $\eta = 0$, which gives the condition $Y > 0$ again.

Case 4. From Equation (A34), we infer $2lo\eta = q - m^{-1}G_0^e(1-\delta) - (1-\delta+w)(k_0 - 2a_0 l)$. Substitute it into Equation (A38), we get

$$\frac{1+r^i}{1-\delta} + (1-\delta) - \frac{q - m^{-1}G_0^e(1-\delta)}{k_0 - 2a_0 l} > 0. \tag{A40}$$

Summarizing the four cases, we have the following two technical conditions.

Technical Condition 1.

$$(1+R^i) - (1+R^e)\frac{f_X}{X_0} > 0. \tag{A41}$$

Technical Condition 2.

$$\frac{1+r^i}{1-\delta} + (1-\delta) - \frac{q - m^{-1}G_0^e(1-\delta)}{k_0 - 2a_0 l} > 0. \tag{A42}$$

B.1.2 Positive demand for collateral commodity

We also conjectured that $C_0^i > 0$, that is, a positive amount of commodity is imported as collateral. By Equation (A29), this condition is

$$q - (1-\delta+w)S_0^i > 2lo\eta. \tag{A43}$$

In Case 1 and Case 3, this condition is equivalent to $S_0^i < q/(1-\delta+w)$. In Case 4, $C_0^i = G_0^e > 0$. In Case 2, if R^i increases by one unit, the left-hand side of Equation (A43) increases by $S_0^i/(1-\delta)$ units, but the right-hand side increases by

$$2lo\frac{S_0^i m/(1-\delta)}{2l(om + zn/X_0)} < \frac{S_0^i}{1-\delta}$$

units. To guarantee Equation (A43) for all $\eta > 0$, it suffices to guarantee Equation (A43) for $\eta = 0$, which again leads to $S_0^i < q/(1-\delta+w)$. Summarizing these cases, we have

Technical Condition 3. In Proposition 1, we have

$$S_0^i < \frac{q}{1-\delta+w}, \tag{A44}$$

where S_0^i is evaluated at the equilibrium levels in these cases.

Note that this condition is satisfied trivially in Case 4 (see above).

Appendix C. Monthly Regressions with China's Macroeconomic Conditions

In Section 6, we showed in weekly regressions that the main empirical results of this paper are robust to the inclusion of China's macroeconomic conditions as control variables. As a further check, in this appendix we rerun the regressions using a monthly sample, where for each month we take the observation on the last Friday. Tables A2, A3, and A4 report the results. As we can see, although we lose three-quarters of the data in the monthly regressions, most coefficients for $\Delta\hat{Y}_t$ and $\tilde{I}_{i,t}\hat{Y}_t$ remain positive and statistically significant, with similar or even larger economic magnitude than in weekly regressions reported in Section 6.

Table A2
Collateral demand and commodity prices in China, controlling for China's macroeconomic conditions, monthly

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber
$\Delta\hat{Y}_t$	5.158**	6.096	4.833	3.614*	5.447*	3.463*	2.898	1.172	3.755	6.487
	(3.05)	(1.97)	(1.74)	(2.18)	(2.32)	(2.25)	(1.71)	(1.21)	(1.75)	(1.85)
$\Delta y_{i,t}$	0.101	0.0303	−0.0326	0.172**	0.203**	0.189**	0.276**	0.370**	0.176**	0.158**
	(1.62)	(0.18)	(−0.25)	(3.05)	(5.22)	(11.48)	(6.83)	(17.06)	(6.92)	(2.88)
$\Delta\gamma_t$	−1.115	0.268	−1.422	0.191	−4.591**	0.247	−0.294	−0.578	1.360	0.691
	(−0.79)	(0.16)	(−0.79)	(0.22)	(−2.89)	(0.89)	(−0.20)	(−1.81)	(0.58)	(0.24)
$MPC_{1,t}$	0.0595	0.100	−0.0130	0.0576	0.0904*	0.122**	0.0834**	0.0505**	0.140*	0.195**
	(1.47)	(1.21)	(−0.32)	(1.43)	(2.65)	(3.81)	(3.47)	(3.27)	(2.03)	(2.82)
$MPC_{2,t}$	0.274**	0.374**	0.431**	0.212**	−0.0633	0.115	0.00352	0.0380	0.160	0.265**
	(2.91)	(3.17)	(6.72)	(3.28)	(−1.42)	(1.59)	(0.07)	(0.97)	(1.16)	(2.76)
$MPC_{3,t}$	0.0905	0.119	0.145	0.0650	0.0765	0.0607	0.0530	−0.0276	0.00303	0.272
	(1.20)	(1.30)	(1.13)	(1.13)	(0.82)	(0.71)	(0.68)	(−0.58)	(0.03)	(1.83)
$MPC_{4,t}$	0.0294	0.155	−0.0939	−0.0399	0.226**	0.105	−0.0304	0.0359	0.208	0.145
	(0.36)	(1.29)	(−0.77)	(−0.59)	(2.81)	(1.13)	(−0.32)	(1.21)	(1.32)	(0.99)
$MPC_{5,t}$	0.211	0.538	−0.249	0.253	0.845**	0.578**	0.544**	0.165	0.975**	0.607
	(0.77)	(1.73)	(−0.91)	(1.97)	(3.57)	(3.09)	(3.39)	(1.47)	(2.73)	(1.73)
$MPC_{6,t}$	0.0563	−0.335	0.460	0.481*	0.461	−0.104	−0.484	0.0119	−0.278	0.463
	(0.12)	(−0.65)	(1.12)	(2.37)	(0.81)	(−0.29)	(−0.88)	(0.03)	(−0.59)	(0.77)
Observations	349	96	90	96	67	384	96	96	96	96
Adjusted R^2	0.144	0.155	0.096	0.264	0.335	0.448	0.459	0.655	0.580	0.249

t-statistics in parentheses.
* $p < 0.05$, ** $p < 0.01$.
All regressions of this table are run at monthly frequency. Columns (1) and (6) report results from the panel regression for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 12 lags. All constants in regressions are suppressed in outputs.

Table A3
Collateral demand and commodity prices in developed markets, controlling for China's macroeconomic conditions, monthly

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber
$\Delta \hat{Y}_t$	7.054**	8.412*	6.666**	5.686**	3.358	6.061*	3.676	5.199	7.625*	7.592*
	(3.49)	(2.28)	(3.51)	(4.72)	(0.81)	(2.52)	(1.48)	(1.82)	(2.57)	(2.41)
$\Delta y_{i,t}$	1.009**	1.395**	1.301**	0.818**	0.329**	0.216**	0.166**	0.200**	0.130	0.249**
	(4.78)	(3.40)	(6.02)	(3.22)	(3.72)	(7.93)	(4.43)	(3.06)	(1.04)	(4.06)
$\Delta \gamma_t$	7.107*	9.010	7.719*	3.947	−14.43	4.564	0.702	0.772	10.87**	5.390
	(2.07)	(1.69)	(2.04)	(1.76)	(−1.11)	(1.05)	(0.25)	(0.23)	(3.21)	(1.14)
$MPC_{1,t}$	0.0395	0.0545	−0.0577	0.116	0.109	0.0984	0.0168	0.0536	0.125	0.194**
	(0.83)	(0.90)	(−1.65)	(1.91)	(1.97)	(1.83)	(0.46)	(1.29)	(1.44)	(2.78)
$MPC_{2,t}$	0.287**	0.335**	0.466**	0.246**	−0.107	0.101	0.00381	0.0388	0.123	0.255*
	(2.88)	(4.18)	(7.83)	(4.07)	(−1.20)	(1.05)	(0.04)	(0.39)	(1.11)	(2.47)
$MPC_{3,t}$	0.149	0.271*	0.188	0.0701	0.0228	0.118	0.0398	−0.0296	0.188	0.274
	(1.56)	(2.50)	(1.44)	(0.68)	(0.25)	(0.88)	(0.25)	(−0.16)	(0.97)	(1.47)
$MPC_{4,t}$	0.0851	0.233*	0.0848	−0.0716	0.0762	0.157	0.131	0.0942	−0.0107	0.393*
	(0.67)	(2.07)	(0.49)	(−0.59)	(0.59)	(1.03)	(0.61)	(0.46)	(−0.08)	(2.31)
$MPC_{5,t}$	0.346	0.554*	0.0561	0.426*	0.843**	0.791**	0.670**	0.926*	1.119**	0.485
	(1.35)	(2.26)	(0.19)	(2.59)	(2.82)	(2.97)	(3.56)	(2.33)	(3.57)	(1.26)
$MPC_{6,t}$	0.397	0.214	0.431	0.872	−0.108	0.835*	0.490	0.882	0.895	1.073
	(0.63)	(0.40)	(0.54)	(1.38)	(−0.16)	(2.02)	(0.70)	(1.23)	(1.33)	(1.69)
Observations	349	96	90	96	67	384	96	96	96	96
Adjusted R^2	0.262	0.296	0.281	0.281	0.024	0.240	0.108	0.107	0.254	0.366

t-statistics in parentheses.
* $p < 0.05$, ** $p < 0.01$.
All regressions of this table are run at monthly frequency. Columns (1) and (6) report results from the panel regression for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 12 lags. All constants in regressions are suppressed in outputs.

Table A4
Inventory–convenience yield relation in China, controlling for China's macroeconomic conditions, monthly

	(1) Metals	(2) Copper	(3) Zinc	(4) Aluminum	(5) Gold	(6) Nonmetals	(7) Soybean	(8) Corn	(9) Fuel Oil	(10) Rubber
$\tilde{I}_{i,t}\hat{Y}_t$	6.330**	3.354	3.098	3.236	14.79**	1.555	1.842	−1.035	−9.475	−9.309
	(5.60)	(0.99)	(1.03)	(0.98)	(2.84)	(0.87)	(0.75)	(−0.38)	(−0.92)	(−1.44)
$\tilde{I}_{i,t}$	−0.0950**	−0.0960*	−0.0772	−0.104**	−0.103*	−0.0252	0.0171	−0.0159	0.0523	0.0559
	(−15.43)	(−2.49)	(−1.59)	(−3.75)	(−2.07)	(−0.91)	(0.75)	(−0.49)	(0.44)	(0.69)
$MPC_{1,t}$	−0.189	−0.391**	−0.455**	0.153	0.297	−0.109	−0.504**	−0.0875	0.614*	−0.732**
	(−1.07)	(−3.33)	(−2.81)	(1.32)	(1.82)	(−0.41)	(−2.88)	(−0.71)	(2.23)	(−3.56)
$MPC_{2,t}$	−0.00651	−0.0338	0.0423	0.451**	−0.361**	−0.975*	−1.116**	0.199	−1.166	−1.965**
	(−0.04)	(−0.28)	(0.33)	(3.50)	(−2.92)	(−2.37)	(−3.54)	(0.75)	(−1.56)	(−3.74)
$MPC_{3,t}$	−0.109	0.0547	−0.0299	0.0157	−0.395	−0.203	−1.376*	−0.533	−1.146	1.311
	(−1.47)	(0.29)	(−0.09)	(0.06)	(−1.91)	(−0.46)	(−2.30)	(−1.95)	(−1.15)	(1.62)
$MPC_{4,t}$	0.200	0.490**	0.379	0.483**	−0.192	0.0910	−0.554	−1.062	1.029	−0.464
	(1.20)	(2.66)	(1.04)	(2.72)	(−0.65)	(0.26)	(−0.84)	(−1.72)	(0.46)	(−0.81)
$MPC_{5,t}$	−0.446	−0.910	0.550	−1.231**	1.496*	0.138	1.286	−1.543**	2.369	−0.900
	(−1.10)	(−1.92)	(0.51)	(−4.09)	(2.33)	(0.17)	(1.66)	(−2.98)	(1.94)	(−0.67)
$MPC_{6,t}$	−1.994	0.338	0.228	−4.258**	−1.492	2.729	6.751**	−0.238	5.116	−5.058
	(−1.16)	(0.63)	(0.11)	(−4.50)	(−0.54)	(1.63)	(4.80)	(−0.13)	(1.94)	(−1.59)
$\tilde{I}_{i,t} \cdot MPC_{1,t}$	−0.0582	0.328*	0.329**	−0.188	−0.125	0.0242	0.403*	0.141	−0.371	0.563**
	(−0.49)	(2.51)	(3.11)	(−1.71)	(−1.13)	(0.15)	(2.18)	(1.49)	(−0.93)	(5.55)
$\tilde{I}_{i,t} \cdot MPC_{2,t}$	0.561**	0.167	−0.146	0.0811	−0.0362	0.658**	0.314	0.571*	0.117	0.289
	(2.89)	(0.68)	(−0.63)	(0.26)	(−0.10)	(3.05)	(1.08)	(2.22)	(0.15)	(0.53)
$\tilde{I}_{i,t} \cdot MPC_{3,t}$	−0.0152	−0.311	0.228	−0.250	−0.168	−0.152	0.272	0.236	−0.607	−1.436
	(−0.30)	(−1.69)	(0.98)	(−0.99)	(−1.15)	(−0.50)	(0.63)	(0.81)	(−0.66)	(−1.95)
$\tilde{I}_{i,t} \cdot MPC_{4,t}$	0.156	−0.921*	0.146	−0.260	0.423	−0.0792	0.405	−0.249	1.462	0.410
	(0.94)	(−2.44)	(0.29)	(−0.50)	(1.54)	(−0.20)	(0.61)	(−0.50)	(1.66)	(0.57)
$\tilde{I}_{i,t} \cdot MPC_{5,t}$	−1.263**	−0.186	0.768	−0.415	−0.903	0.436	−1.456	0.682	2.693*	2.533
	(−2.81)	(−0.37)	(1.21)	(−0.56)	(−0.86)	(0.66)	(−1.86)	(0.72)	(2.40)	(1.62)
$\tilde{I}_{i,t} \cdot MPC_{6,t}$	−0.361	−1.782	0.543	1.053	2.033	1.049	−0.0593	2.969**	3.082	−2.290
	(−0.37)	(−1.87)	(0.38)	(1.09)	(0.66)	(0.97)	(−0.02)	(2.81)	(0.90)	(−0.64)
Observations	341	97	79	97	68	376	97	97	97	85
Adjusted R^2	0.386	0.543	0.411	0.576	0.117	0.179	0.243	0.267	0.013	0.425

t-statistics in parentheses.
* $p<0.05$, ** $p<0.01$.
All regressions of this table are run at monthly frequency. Columns (1) and (6) report results from the panel regression for the metal group and nonmetal group, where standard errors are double-clustered by commodity and date, as in Petersen (2009). Columns (2)–(5) and (7)–(10) report results for individual commodities, where standard errors are calculated using the Newey-West method with 12 lags. All constants in regressions are suppressed in outputs.

References

Acharya, V. V., L. A. Lochstoer, and T. Ramadorai. 2013. Limits to arbitrage and hedging: Evidence from commodity markets. *Journal of Financial Economics* 109:441–65.

Asia Securities Industry and Financial Markets Association. 2014. RMB roadmap. Technical report.

Baker, S. D. 2014. The financialization of storable commodities. Working paper.

Basak, S. and A. Pavlova. (2013). A model of financialization of commodities. Working paper.

Bessembinder, H. 1992. Systematic risk, hedging pressure, and risk premiums in futures markets. *Review of Financial Studies* 5:637–67.

Brennan, M. J. 1958. The supply of storage. *American Economic Review* 48:50–72.

Chang, E. C. 1985. Returns to speculators and the theory of normal backwardation. *Journal of Finance* 40: 193–208.

Cheng, I.-H., A. Kirilenko, and W. Xiong. 2015. Convective risk flows in commodity futures markets. *Review of Finance* 19:1733–81.

Cheng, I.-H. and W. Xiong. 2014. Financialization of commodity markets. *Annual Review of Financial Economics* 6:419–41.

Desai, M. A., C. F. Foley, and J. R. Hines. 2006. Capital controls, liberalizations, and foreign direct investment. *Review of Financial Studies* 19:1433–64.

Duffie, D. 2010. Presidential address: Asset price dynamics with slow-moving capital. *Journal of Finance* 65:1237–67.

Duffie, D. and B. Strulovici. 2012. Capital mobility and asset pricing. *Econometrica* 80:2469–509.

Dusak, K. 1973. Futures trading and investor returns: An investigation of commodity market risk premiums. *Journal of Political Economy* 81:1387–406.

Economic Observer. 2012. The risk of bad debts accumulated, banks check copper financing. [In Chinese.]

Elliott, D., A. Kroeber, and Y. Qiao 2015. Shadow banking in China: A primer. Working paper.

Frankel, J. 2006. The effect of monetary policy on real commodity prices. NBER working paper 12713.

Frankel, J. A. 1986. Expectations and commodity price dynamics: The overshooting model. *American Journal of Agricultural Economics* 68:344–8.

Fu, X. 2014. Copper & iron ore: Are Chinese financing deal fears overdone? Deutsche Bank Market Research.

Garvey, M. and A. Shaw. 2014. Base metals: Copper–collateral damage. Credit Suisse Fixed Income Research.

Gorton, G. B., F. Hayashi, and K. G. Rouwenhorst. 2013. The fundamentals of commodity futures returns. *Review of Finance* 17:35–105.

Hamilton, J. and J. Wu. 2015. Effects of index-fund investing on commodity futures prices. *International Economic Review* 56:187–205.

Henderson, B. J., N. D. Pearson, and L. Wang. 2015. New evidence on the financialization of commodity markets. *Review of Financial Studies* 28:1285–311.

Hirshleifer, D. A. 1990. Hedging pressure and futures price movements in a general equilibrium model. *Econometrica* 58:411–58.

International Copper Study Group. 2013. The world copper factbook 2013. Technical report.

International Monetary Fund. 2012. The liberalization and management of capital flows: An institutional view. Technical report.

Keynes, J. M. 1923. Some aspects of commodity markets. *Manchester Guardian Commercial* 13:784–6.

Kiyotaki, N. and J. Moore. 1997. Credit cycles. *Journal of Political Economy* 105:211–48.

Knittel, C. R. and R. S. Pindyck. 2013. The simple economics of commodity price speculation. Working paper.

Kolb, R. W. 1992. Is normal backwardation normal? *Journal of Futures Markets* 12:75–91.

Moffett, M. H., A. I. Stonehill, and D. K. Eiteman. 2011. *Fundamentals of Multilateral Finance*. Prentice Hall.

Ostry, J. D., A. R. Ghosh, K. Habermeier, M. Chamon, M. S. Qureshi, and D. B. Reinhardt. 2010. Capital inflows: The role of controls. IMF staff position note.

Pasquariello, P. 2014. Financial market dislocations. *Review of Financial Studies* 27:1868–914.

Petersen, M. A. 2009. Estimating standard errors in finance panel data sets: Comparing approaches. *Review of Financial Studies* 22:435–80.

Pindyck, R. S. 1993. The present value model of rational commodity pricing. *Economic Journal* 103:511–30.

Pindyck, R. S. 2001. The dynamics of commodity spot and futures markets: A primer. *Energy Journal* 22:1–29.

Rockwell, C. S. 1967. Normal backwardation, forecasting and the returns to commodity futures traders. *Food Research Institute Studies* 7:107–30.

Rogoff, K. S. 2002. Rethinking capital controls: When should we keep an open mind? *Finance and Development* 39.

Routledge, B. R., D. J. Seppi, and C. S. Spatt. 2000. Equilibrium forward curves for commodities. *Journal of Finance* 55:1297–338.

Rouwenhorst, K. G. and K. Tang. 2012. Commodity investing. *Annual Review of Financial Economics* 4:447–67.

Singleton, K. J. 2014. Investor flows and the 2008 boom/bust in oil prices. *Management Science* 60:300–18.

Sockin, M. and W. Xiong. 2015. Informational frictions and commodity markets. *Journal of Finance* 70:2063–98.

Tang, K. and W. Xiong. 2012. Index investment and the financialization of commodities. *Financial Analysts Journal* 68:54–74.

Telser, L. G. 1958. Futures trading and the storage of cotton and wheat. *Journal of Political Economy* 66:233–55.

Working, H. 1960. Price effects of futures trading. *Food Research Institute Studies* 1:3–27.

World Steel Association. 2013. Steel statistical yearbook 2013. Technical report.

Yu, J. 2007. Closed-form likelihood approximation and estimation of jump-diffusions with an application to the realignment risk of the Chinese Yuan. *Journal of Econometrics* 141:1245–80.

Yuan, R., M. Layton, and J. Currie. 2013. Copper: Beware the red herring. Goldman Sachs Commodities Research.

Yuan, R., M. Layton, J. Currie, and D. Courvalin. 2014. Days numbered for Chinese commodity financing deals. Goldman Sachs Commodities Research.