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Price Transmission and Effects of Exchange Rates on Domestic Commodity Prices via Offshore and Currency Hedging

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The framework presents how trading in the foreign commodity futures market and the forward exchange market can affect the optimal spot positions of domestic commodity producers and traders. It generalizes the models of Kawai and Zilcha (1986) and Kofman and Viaene (1991) to allow both intermediate and final commodities to be traded in the international and futures markets, and the exporters/importers to face production shock, domestic factor costs and a random price. Applying mean-variance expected utility, we find that a rise in the expected exchange rate can raise both supply and demand for commodities and reduce domestic prices if the exchange rate elasticity of supply is greater than that of demand. Whether higher volatilities of exchange rate and foreign futures price can reduce the optimal spot position of domestic traders depends on the correlation between the exchange rate and the foreign futures price. Even though the forward exchange market is unbiased, and there is no correlation between commodity prices and exchange rates, the exchange rate can still affect domestic trading and prices through offshore hedging and international trade if the traders are interested in their profit in domestic currency. It illustrates how the world prices and foreign futures prices of commodities and their volatility can be transmitted to the domestic market as well as the dynamic relationship between intermediate and final goods prices. The equilibrium prices depends on trader behaviour i.e. who trades or does not trade in the foreign commodity futures and domestic forward currency markets. The empirical result applying a two-stage-least-squares approach to Thai rice and rubber prices supports the theoretical result.

Keywords: commodity markets, offshore hedging, currency hedging, asset pricing, price transmission

JEL Classification: F1; F3; G1; Q1

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1. Introduction

Many frameworks try to explain the behaviour of traders and commodity prices in an economy that has both commodity spot and futures markets. However, some small countries are the world's largest exporters or importers of commodities, and they do not have their own commodity futures market. The domestic traders in these small countries are price takers. The world prices can therefore affect domestic commodity prices, and higher volatility of world prices can have an adverse effect on these small economies. For example, in the first half of 2008 the rise in oil prices raised the demand for biofuel and pushed up the prices of sugar and starch crops (e.g. corn, wheat and rice). It also increased production costs of synthetic rubber and thus increased the demand for substitutes (e.g. natural rubber). Many importing countries such as South Korea, Taiwan and the Philippines suffered from these changes while exporting countries had higher export incomes and simultaneously faced economic instability due to higher volatility of commodity prices. For instance, Thailand, which is the world's largest exporter of milled rice, sugar and rubber products, benefited from commodity price rises. That is, Thai export growth increased, and thus Thailand experienced a resilient economic growth in spite of facing higher fuel import bills. However, at the same time Thai people suffered from a continuous increase in the domestic prices of rice and sugar, which are the main food staples of the country; more rice and sugar were exported due to the higher world prices, leaving the country with a lower supply. Later, the commodity prices dropped following a sharp fall in oil prices in July 2008. This caused a decrease in Thai export growth, farm incomes and the profits of mills as well as rubber sheet manufacturers, leading to a reduction of private consumption growth. As a result, economic growth dropped from 0.8% y-o-y in the first half of 2008 to -0.7 and -4.9% y-o-y in the third and fourth quarters of 2008, respectively.

From this, we can see that traders facing price risk are not only exporters, but also producers, processors and storage companies. Without a domestic futures market, domestic traders can only

hedge their price risk in the foreign commodity futures markets or use the foreign futures prices as information in predicting future commodity prices. For example, before the Agricultural Futures Exchange of Thailand (AFET) started trading futures contracts for smoked rubber sheets in May 2004 and futures contracts for milled rice in August 2004, Thai rubber traders hedged their price risk in the Singapore Commodity Exchange (SICOM) or used the SICOM's smoked rubber sheet futures prices to forecast the future price of rubber[1] and Thai rice traders traded on the Chicago Board of Trade (CBOT) or used the CBOT's rough rice price to forecast the future price of rice[2]. This raises a concern about whether exchange rates can affect domestic commodity prices also through foreign futures trading.

Kawai and Zilcha (1986) found that if an economy has only a forward foreign exchange market, exports can be increased by the introduction of domestic commodity futures markets. Many recent papers have computed the optimal offshore hedging strategy for exporters or importers. Kawai and Zilcha (1986) and Kofman and Viaene (1991) found the exporters' optimal strategy in the case of incomplete markets where there is no commodity futures market in the economy. Their models focused on an intermediate commodity which was storable, quoted in the foreign demanding country's currency and traded in the international and futures markets. Jin and Koo (2002) developed a theoretical model to find a hedging strategy when the traders face hedging costs; in their empirical work they also found the optimal hedging ratio for Japanese wheat importers who hedged their price risk in the CBOT and hedged exchange rate risk in the Tokyo International Financial Futures Exchange (TIFFE). Empirically, Yun and Kim (2010) found that Korean oil importers' hedging would be more effective if they hedged their price risk in the foreign futures market and simultaneously entered into currency futures contracts. While these models have focused on optimal strategies for exporters of intermediate commodities, some small countries allow exports of final goods only e.g.

[1] There are more Thai traders trading the futures contract of smoked rubber sheet in the SICOM than in other futures market because the Singapore is the largest port shipping smoked rubber sheet for Thailand and Malaysia, the world largest exporters of smoked rubber sheet.

[2] For the case of rice, there are more Thai traders trading in the CBOT than in other futures market because the US is one of the largest importers of Thai milled rice. However, rice traded at the CBOT is rough rice, not milled rice.

Thai rough rice and natural rubber cannot be exported due to the nature of the products, a much higher delivery cost, and regulations. For some commodities e.g. sugar and oil, both intermediate and final commodities (raw sugar and refined sugar, or crude oil and refined oil) can be exported. Unlike others, Kofman and Viaene (1991) specified the optimal offshore hedging strategy of domestic processors as well as their exporting counterparts.

Some papers have focused on analysing the empirical relationship between exchange rates and world commodity prices. Investigating the relation between the world price of milled rice (Thai milled rice price) and the Thai Baht (THB)-US Dollar (USD) exchange rate, Kofman and Viaene (1991) found a positive ex-post correlation coefficient while Gilbert (1991) found that the exchange rate elasticity was equal to -1. Applying a Granger Causality test, Timmer (2009) found that the Euro-USD exchange rate significantly Granger caused the world prices of commodities e.g. rice, corn, wheat, crude oil and palm oil. Using the world commodity price indices, Chen, Rogoff and Rossi (2010) showed that exchange rates had significant power in forecasting commodity prices. While world prices and domestic prices can be highly correlated, they are unnecessarily equal. It is interesting to know how exchange rates can affect domestic commodity prices too, especially through trading activities other than exporting or importing.

An aim of this paper is to develop a framework to explain the effects of trading in the foreign commodity futures and domestic currency markets on the domestic commodity market of a small country; it also examines how exchange rates can affect domestic commodity prices through this trading. The framework here expands the models of Kawai and Zilcha (1986) and Kofman and Viaene (1991), allowing both intermediate and final commodities to be traded in the international market. The futures market can trade either the intermediate commodity or final commodity. Some of their assumptions are also relaxed e.g. exporters and importers face export and import uncertainties, as well as domestic factor costs. By applying a two-period mean-variance approach[3], the agents' optimal commodity spot and futures holdings and optimal forward exchange holding in this particular case are

[3] Cochrane (2001) has proved that if the condition holds at each period, then the infinite-period and two-period consumption-based models can give equivalent results.

specified. Unlike the framework for a country which has its own futures markets, the framework in this paper shows that the degree of risk aversion can affect the optimal spot position when the country does not have its own futures market. We then derive the equilibrium prices in the domestic commodity markets. We find that relationships among optimal strategies, equilibrium prices, and exchange rates depend upon not only whether commodity prices and the exchange rates are correlated, but also which product is exported, whether exports are contracted in advance, and which traders hedge their price and exchange rate risks. Even if the forward foreign exchange rate is unbiased and there is no correlation between commodity prices and exchange rates, there are still some exchange rate effects on the commodity prices via exporting/importing and trading in the foreign futures market if the agents are interested in their profits in domestic currency. Higher volatilities of the exchange rate and the foreign futures price can affect the optimal forward position, and thus the optimal futures and spot positions. The framework also shows how world prices are transmitted to domestic intermediate and final commodity markets. Higher volatilities of domestic and world prices of the commodity will reduce both demand and supply of the commodity, but their impacts on price will depend on whether supply or demand is affected more.

For empirical analysis, we use data on Thai rice and Thai rubber prices as well as the exchange rates of the THB against the USD and Singapore Dollar (SGD) before futures contracts were first traded in the AFET. Our empirical findings support the theoretical result arrived at. With the exception of the correlation between the exchange rate and the world price of smoked rubber sheets (in domestic currency), contemporaneous correlations of exchange rates with commodity prices (in domestic currency) are insignificant in both commodity markets. The inefficient forward exchange market allows the forward exchange rate to have a direct impact on the optimal spot position and the prices in the rubber markets.

The rest of the paper is structured as follows. In the next section, the theoretical framework is developed to find the optimal strategies and equilibrium prices. In Section 3, a two-stage-least-squares regression analysis shows how prices of intermediate and final commodities are related and how they are affected by world prices, foreign futures prices and exchange rates. Section 4 concludes and

suggests some further research.

2. Framework

2.1 Assumptions

In this framework, both intermediate and final commodities are storable and internationally tradable in a small country which does not have its own commodity futures market, but has a spot commodity market and a forward exchange market. The two-period mean-variance expected utility maximization is applied to find the optimal strategies of domestic traders: producers, processors, exporters (or importers), and storage companies. Production and trade flows among domestic traders of intermediate and final commodities of an exporting country and an importing country are shown in Figure 1(a) and Figure 1(b), respectively.

[Insert Figure 1 about here]

We assume that the production process, storage and international delivery take one period (i.e. traders hold the positions for a single-period horizon), and in each period both intermediate and final commodities are traded in domestic and international markets. The intermediate producers choose the optimal level of input (e.g. primary commodity) at period t to produce the intermediate commodity and sell their output to the domestic market at period $t+1$ at price P_{t+1}. With the optimal level of input (intermediate commodity) chosen at period t, processors produce the final commodity and sell it to domestic storage companies and exporters at period $t+1$ at price Q_{t+1}. Storage companies can hold a spot position in the domestic market of intermediate or final commodity and close their position in the next period to make a profit. In the framework of an exporting country, exporters buy the commodities from the domestic market; after packaging the exporters deliver the commodities to the foreign importers and get paid in foreign currency in the next period at the world prices (P_{mt+1} and Q_{mt+1} which are quoted in foreign currency). In the framework for a country which is the world's importer of commodities, importers buy commodities from abroad at the world prices (P_{mt} and Q_{mt}) at

period t and sell them to the domestic market after receiving commodities in the next period at price (P_{t+1} and Q_{t+1}).

Π_i is the profit of trader i where $i=f$ for the intermediate producers, $i=p$ for the processors, $i=s$ for the storage companies and $i=e$ for the exporters. Note that in period t, all stochastic variables of time $t+1$ are unknown. In the sequel, X_{it} denotes the position of the tader of type i in the primary good at time t and similarly for Y_{it} (intermediate good), H_{it} (final good), Y_{it}^f (futures contract for the intermediate or final commodity) and Z_{it}^f (the forward exchange contract). The framework also has assumptions as follows.

Assumption 1: As the country does not have a commodity futures market, domestic traders can hedge their price risk in the foreign commodity futures market, in which either the intermediate or final commodity is traded. The futures prices are quoted in foreign currency. Traders can enter into the futures contract with a full margin at time t which is worth $Y_{it}^f F_t e_t$ in domestic currency. The maturity of the futures and forward contracts is at time $t+1$. It follows that all domestic traders close their futures position by the last trading day of period $t+1$ by a cash settlement because delivering to or taking delivery from the foreign futures market requires substantial additional costs, or the commodity traded in the foreign futures market is different from the commodity of which price risk is hedged. Therefore, all traders transfer the cash (in foreign currency) through the clearinghouse both at time t and $t+1$ i.e. the payment on $Y_{it}^f F_t$ is made at time t with the exchange rate e_t and the payment on $Y_{it}^f F_{t+1}$ is made at time $t+1$ to close futures position with the exchange rate e_{t+1}.

Assumption 2: Due to international trade and foreign futures trading, traders face exchange rate risk. To hedge exchange rate risk, traders can short or long the forward exchange contract at time t, based on the expected future payment or receipt (in foreign currency). Unlike the trade in the futures market, there is no margin requirement in the forward market so the payment in the forward exchange market is only made at maturity $t+1$. After the cash transfer, the foreign currency remaining in their hands can be sold to the spot exchange market. If their actual payment (receipt) in foreign currency is larger (smaller) than Z_{it}^f, they can also buy more foreign currency in the spot market.

Assumption 3: At time t, all traders choose their optimal decisions by maximising their expected utility function (V) depending on their profit in domestic currency. Any variables such as the optimal spot and futures positions chosen by trader i at time t depend on his own information set available at time t (I_{it}). $E_{it}(\ )$ denotes trader i's expectation depending on I_{it}. $Var_{it}(\ )$ denotes trader i's expected variance of a variable depending on I_{it}. The discount factor, ρ, is assumed to be $1/(1+i_{t+1})$ where i_{t+1} is the domestic interest rate at time $t+1$ and perfectly foreseen at time t.

Assumption 4: Domestic traders in a commodity market are rational and are small in the international commodity market, foreign futures market and forward exchange market relatively to trading volume in the markets. So here we derive only the equilibrium prices in the domestic commodity spot markets. With this assumption, the expected future exchange rate perceived by trader i ($E_{it}(e_{t+1})$) equals the expected exchange rate perceived by the market ($E_t(e_{t+1})$). Unlike the assumption of Battermann, Braulke, Broll and Schimmelpfennig (2000), here $E_{it}(e_{t+1})$ is not necessarily equal to the forward exchange rate, f_t i.e. $f_t = E_t(e_{t+1}) +$ risk premium. This risk premium can be time varying.

Assumption 5: Production shock, storage and export uncertainty, noise trading in the commodity futures and forward foreign exchange markets are uncorrelated and do not have serial correlations. The domestic spot and forward exchange markets are insignificantly affected by production shock, storage uncertainty and the uncertainty of commodity futures prices.

Assumption 6: The commodity prices in domestic and international markets can be different. Many exported commodities are important commodities for the exporting countries and thus the domestic agricultural sector is protected by the government through its intervention schemes[4].

2.2 Profit Functions

Intermediate producers

A producer buys seeds (the primary commodity) at time t to produce the intermediate

[4] For instance, while rice and sugar are main export products of Thailand, they are the main food of the country too. For rough rice, the government may set a guarantee price at which the government will buy from farmers and provide cheap loans for farmers e.g. the rice-mortgage scheme was introduced in September 2011; under this scheme, the government buys rice from farmers at about twice of the normal market price. For sugar which is main ingredient of Thai food, the government sets a ceiling price to help consumers and processors.

commodity and sells his output $f(X_{ft}, l, \varepsilon_{t+1})$ [5] in the spot market at time *t+1*. We assume that the production shock, ε_{t+1} has $E_{ft}(\varepsilon_{t+1})=0$ and $Var_{ft}(\varepsilon_{t+1})= \sigma_{\varepsilon}^2$. The production shock is realised just before delivering the output to the spot market at time *t+1*. θX_{ft}^2 is the production cost excluding the cost of seeds (θ>0). He can hedge his price risk by selling futures contracts maturing at time *t+1*, Y_{ft}^f, at price F_t in the foreign futures market at time *t*. His profit function is, therefore,

$$\Pi_f = \Phi_t Y_{ft}^f - r_t X_{ft} - \theta X_{ft}^2 + \rho\{P_{t+1}(f(X_{ft}) + \varepsilon_{t+1}) - \Phi_{t+1} Y_{ft}^f + (e_{t+1} - f_t) Z_{ft}^f\}.$$

where r_t is the primary commodity price and Φ_t (= $F_t e_t$) is the foreign futures price (F_t) at time *t* converted into the unit of domestic currency using the exchange rate e_t. Because of closing futures position with cash settlement, he faces exchange rate risk which he can hedge by buying forward exchange contracts maturing at time *t+1*, Z_{ft}^f, at the forward rate f_t. After taking delivery of the amount of foreign currency Z_{ft}^f from the forward exchange market, he may sell his excess foreign currency $Z_{ft}^f - Y_{ft}^f F_{t+1}$ in the spot exchange market at *t+1* if his actual payment (in foreign currency) to the futures market at time *t+1* is smaller than Z_{ft}^f. On the other hand, he may buy more foreign currency from the spot exchange if $Z_{ft}^f < Y_{ft}^f F_{t+1}$. Alternatively, he may choose to buy the exact amount of the foreign currency which he has to pay to the futures market from the spot exchange market at time *t+1* at the rate e_{t+1} and thus $Z_{ft}^f = 0$.

Processors

At time *t,* a processor purchases the intermediate commodity to produce the final commodity $H_{pt+1} = g(Y_{py}, k, v_{t+1})$ [6]. We assume that the production shock, v_{t+1}, is realised just before delivering the output to the spot market at time *t+1* and that v_{t+1} has a zero mean and a constant

[5] $Y_{ft+1} = \min\{bX_{ft+1}, l^{1/2}\} + \varepsilon_{t+1}$ where l is other inputs and 0<*b*<1. Therefore, the cost function is equal to the cost of seeds and the other production cost which depends on the amount of input used in the production.

[6] $H_{pt+1} = \min\{a(Y_{pt}), k^{1/2}\} + v_{t+1}$ where k is other inputs and 0<*a*<1. Therefore, the cost function is equal to the cost of intermediate goods and the other production cost which depends on the amount of intermediate goods used in the production.

variance (σ_v^2). αY_{pt}^2 is the other production cost which depends on the amount of intermediate commodity. He sells his output at time *t+1* in the domestic market at price Q_{t+1}. At time *t*, he can also sell foreign futures contracts of intermediate or final goods maturing at time *t+1* (Y_{pt}^f) to hedge his price risk. Then, at time *t+1*, he closes all of his futures position by buying futures contracts at price F_{t+1}. He can also hedge his exchange rate risk by buying the forward exchange contract, Z_{pt}^f. After taking delivery of Z_{pt}^f, he may buy more (sell excess) foreign currency in the spot exchange market if it turns out that he has underhedged (overhedged) his exchange rate risk. Instead, he may choose not to hedge his exchange rate risk ($Z_{pt}^f = 0$), and then buy $Y_{pt}^f F_{t+1}$ in the spot exchange market at the rate e_{t+1} at time *t+1*. Consequently, a processor's profit function is

$$\Pi_p = \Phi_t Y_{pt}^f - P_t Y_{pt} - \alpha Y_{pt}^2 + \rho\{Q_{t+1}(g(Y_{pt}) + v_{t+1}) - \Phi_{t+1} Y_{pt+1}^f + (e_{t+1} - f_t) Z_{pt}^f\}$$

Storage companies

A storage company purchases the intermediate or final commodity from the domestic market at time *t+1* and sells it to the domestic market at time *t+1* to make a profit. The storage cost is γY_{st}^2 for the company storing the intermediate commodity and γH_{st}^2 for the company storing the final commodity where 0<γ<1. w_{t+1}^y and w_{t+1}^h denote storage uncertainties for the intermediate commodity and the final commodity, respectively. We assume that both uncertainties have mean values of zero and constant variances and that $Cov(w_{t+1}^y,\ w_{t+1}^h) = 0$. At time *t*, the manager can hedge his price risk by selling the futures contract maturing at time *t+1* at price F_t. He then closes his futures position in the period *t+1* at price F_{t+1}. In addition, he can hedge his exchange rate risk due to the payment to the futures market at time *t+1* with the forward exchange contract at the forward rate, f_t. Like other trader types, he may sell excess or buy more in the spot exchange market if he has overhedged or underhedged his exchange rate risk. Or else, he may choose to buy the amount of the foreign currency from the spot exchange market at *t+1* at the rate e_{t+1}. Thereby, the profit of the company that stores the intermediate commodity is

$$\Pi_s = \Phi_t Y_{st}^f - P_t Y_{st} - \gamma Y_{st}^2 + \rho\{P_{t+1}(Y_{st} + w_{t+1}^y) - \Phi_{t+1} Y_{st}^f + (e_{t+1} - f_t) Z_{st}^f\}.$$

For the company that stores the final commodity, the company's profit function is

$$\Pi_s = \Phi_t Y_{st}^f - Q_t H_{st} - \gamma H_{st}^2 + \rho\{Q_{t+1}(H_{st} + w_{t+1}^h) - \Phi_{t+1} Y_{st}^f + (e_{t+1} - f_t) Z_{st}^f\}.$$

International Trade: Exporters/Importers

At time *t*, an exporter commits to export the intermediate or final commodity, so he purchases the commodity at time *t* and export it at price (P_{mt+1} or Q_{mt+1}) at time *t+1*. Like Kawai and Zilcha (1986), we assume that export prices at time *t+1* are random. His total production cost is the cost of purchase ($P_t Y_{et}$ or $Q_t H_{et}$) plus delivery and transaction costs (βY_{et}^2 or βH_{et}^2) where 0<β<1. u_{t+1}^y and u_{t+1}^h denote export uncertainties for intermediate goods and final goods. We assume that each has a zero mean and a constant variance and that $Cov(u_{t+1}^y, u_{t+1}^h) = 0$. He can also hedge his price risk in the foreign futures market by selling the futures contract, which matures at time *t+1*, at time *t* and then closing the futures position at time *t+1*. Simultaneously, he can hedge his exchange rate risk due to the payment to the futures market at time *t+1* by purchasing the forward exchange contract at time *t* at the forward rate f_t. He may sell excess in the spot exchange market if it turns out that he has overhedged his exchange rate risk. If he chooses not to hedge his exchange rate risk, he may buy foreign currency from the spot exchange market at *t+1* at the rate e_{t+1}. The profit function of the intermediate goods exporter is

$$\Pi_e = \Phi_t Y_{et}^f - P_t Y_{et} - \beta Y_{et}^2 + \rho\{P_{mt+1} e_{t+1}(Y_{et} + u_{t+1}^y) - \Phi_{t+1} Y_{et}^f + (e_{t+1} - f_t) Z_{et}^f\}.$$

while the final goods exporter's profit function is

$$\Pi_e = \Phi_t Y_{et}^f - Q_t H_{et} - \beta H_{et}^2 + \rho\{Q_{mt+1} e_{t+1}(H_{et} + u_{t+1}^h) - \Phi_{t+1} Y_{et}^f + (e_{t+1} - f_t) Z_{et}^f\}.$$

In the framework of an imported commodity, the importer's input costs is the world prices, P_{mt} and Q_{mt} while the commodity is sold to the domestic market at time *t+1* at the domestic price, P_{t+1} and Q_{t+1}. Given that he makes decision at time *t*, he faces price risk from selling the commodity to the domestic market and also exchange rate risk from offshore hedging.

2.3 Optimal Strategies

Each trader chooses his optimal commodity spot position, commodity futures position and forward exchange position by maximising the mean-variance expected utility depending on their profits. The general form of the profit function for the trader of type *i* is

$$\begin{aligned}\Pi_i &= Y_{it}^f \Phi_t - C_{it} S_{it} - \lambda_i S_{it}^2 + \rho\{M_{it+1}(S_{it} + \xi_{it+1}) - Y_{it}^f \Phi_{t+1} + (e_{t+1} - f_t) Z_{it}^f\} \\ &= \Pi_{it} + \rho(\Pi_{it+1}).\end{aligned}$$

Let S_{it} be the vector of the spot positions i.e. $f(X_{ft}^*)$ for $i=f$, $g(Y_{pt}^*)$ for $i=p$, Y_{it}^* or H_{it}^* for $i=s,e$[7]. M_{it+1} is the price of product sold by the trade of type *i*: P_{t+1} for the producer and the company storing or importing the intermediate commodity, Q_{t+1} for the processor and the company storing or importing the final commodity, P_{mt+1} e_{t+1} for the exporter of the intermediate commodity, and Q_{mt+1} e_{t+1} for the exporter of the final commodity. C_{it} is the input cost per unit of output: r_t/b for the producer, P_t/a for the processor, P_t for the company storing or exporting intermediate goods, Q_t for the company storing or exporting final goods, $P_{mt}e_t$ and $Q_{mt}e_t$ for the importers of intermediate and final commodities. ξ_{it+1} is production shock for the producer and the processor, storage uncertainty for storage companies, and export (import) uncertainty for exporters (importers). The decision is made at time *t*, so the domestic net supply of intermediate and final commodities at time *t+1* depends on the input that producers, processors and storage companies bought at time *t*. The objective function is

$$\underset{S_{it}, Y_{it}^f, Z_{it}^f}{Max}\ V_i = U_{it}(\Pi_{it}) + \rho E_{it} U_{it+1}(\Pi_{it+1})$$

That is, the two-period expected utility is maximised with respect to the spot position (X_{ft} for $i=f$, Y_{it} for $i=p$, and Y_{it} or H_{it} for $i=s,e$), the futures position (Y_{it}^f) and the forward position (Z_{it}^f).

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[7]The optimal spot position of the producer is X_{ft}^* while the optimal spot position for the processor is Y_{pt}^*. From this, we also find the optimal output level at time *t+1* regardless of additive production shocks i.e. $f(X_{ft}^*)$ for the producer and $g(Y_{pt}^*)$ for the processor. For storage companies, the optimal spot position is trading volume, not the stock of commodity, at time *t* which is carried forward to the period *t+1*. The optimal position at time *t* is denoted as Y_{st}^* for the company storing intermediate goods and H_{st}^* for the company storing final goods. Y_{et}^* and H_{et}^* are the optimal positions at time *t* for the exporter of intermediate goods and the exporter of final goods, respectively.

The optimal spot position

Solving the first order conditions (see Appendix A) yields the vector of the optimal spot positions,

$$S_{it}^{*} = \frac{\rho E_{it}(M_{it+1})(1 - A_i Cov_{it}(M_{it+1}, \xi_{it+1})) - C_{it}}{\chi_{it}} + \frac{\Phi_t - \rho E_{it}(\Phi_{t+1})}{\chi_{it}} \left| \sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}} \right| \frac{Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, e_{t+1})}{1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})} \quad (1)$$
$$+ \frac{\rho(E_{it}(e_{t+1}) - f_t)}{\chi_{it}} \left| \sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(e_{t+1})}} \right| \frac{Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1})}{1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})}$$

for all *i* where

$$\chi_{it} = \lambda_i + \rho A_i Var_{it}(M_{it+1}) \{1 - \frac{Corr_{it}^2(M_{it+1}, \Phi_{t+1}) + Corr_{it}^2(M_{it+1}, e_{t+1}) - 2Corr_{it}(M_{it+1}, e_{t+1}) Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, \Phi_{t+1})}{1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})}\}$$
$$> 0$$

where λ_i is equal to $\frac{2\theta}{b^2}$ for the farmer, $\frac{2\alpha}{a^2}$ for the processor, 2γ for the storage company, 2β for the exporters (importers). $\lambda_i = 0$ if there is no other costs apart from the cost of purchase. We assume that $Cov_{it}(M_{it+1}, \xi_{it+1}) < 0$. This is because a decrease in the supply of the commodities due to a negative shock (e.g. weather and rotting) will raise the commodity price.

Unlike Anderson and Danthine (1983), Antoniou (1986), and Benninga and Oosterhof (2004) in which the country has its own futures market, the optimal spot position here depends on trading in other markets and the degree of risk aversion; thus, the separation theorem is not applicable. When the expected gain in the spot, futures or forward market increases, the traders tend to hold a larger spot position. Like Kawai and Zilcha (1986), Kofman and Viaene (1986) and Schmittmann (2010), the failure of uncovered interest rate parity (UIP) allows currency hedging to have a direct impact on the spot position. While higher volatility of domestic and world commodity prices and their correlation with the exchange rate can cause a reduction of the optimal spot position, higher correlation between domestic output prices and foreign futures prices increases the optimal spot position (See Appendix B). Volatilities of the exchange rate and the foreign futures price can affect the optimal spot position; the effects depend on (i) the correlation between the exchange rate and the foreign futures price and

(ii) the effect of the correlation on the optimal spot position. This is supported by the finding of Bahmani-Oskooee and Mitra (2008) that exchange rate volatility has negative impacts on exports and imports of commodities between the US and India. The effects of these on the profit of traders are in the same direction as those on the optimal spot positions if the expected marginal gain of trading in futures and forward markets is non-negative and that the marginal revenue product (MRP) of input is not less than its marginal resource cost (MRC).

If there is no correlation between commodity prices (P_{t+1}, Q_{t+1}, Q_{mt+1}, P_{mt+1}, F_{t+1}) and the exchange rate (e_{t+1}), $E_{it}(\Phi_{t+1}) = E_{it}(F_{t+1})E_{it}(e_{t+1})$ for all i and $E_{it}(M_{it+1})$ for the exporters are $E_{et}(P_{mt+1})E_{et}(e_{t+1})$ and $E_{et}(Q_{mt+1})E_{et}(e_{t+1})$. The correlations of the exchange rate with the foreign futures price and the world prices denominated in domestic currency are still non-zero. Therefore, even though there is no direct relation between commodity prices and exchange rates, the optimal spot positions of traders are still affected by the expected future value and volatility of exchange rate through offshore hedging, currency hedging and international trade.

If the forward market is also unbiased, the last term in profit function disappears for all *i*. Without speculative currency holding or with $Corr_{it}(M_{it+1}, e_{t+1})$=0 and $Corr_{it}(\Phi_{t+1}, e_{t+1})$=0, the optimal position will be

$$S_{it} = \frac{\rho E_{it}(M_{it+1})(1 - A_i Cov_{it}(M_{it+1}, \xi_{it+1})) - C_{it}}{\lambda_i + \rho A_i Var_{it}(M_{it+1})\{1 - Corr_{it}^2(M_{it+1}, \Phi_{t+1})\}} + \frac{[\Phi_t - \rho E_{it}(\Phi_{t+1})] Corr_{it}(M_{it+1}, \Phi_{t+1}) \left| \sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}} \right|}{\lambda_i + \rho A_i Var_{it}(M_{it+1})\{1 - Corr_{it}^2(M_{it+1}, \Phi_{t+1})\}} \quad (2)$$

Equation (2) is not affected directly by the exchange rates but indirectly through foreign futures trading and international trade (see Appendix C). The second term of Equation (1) and (2) is the effect of futures trading. As the denominator of Equation (2) is larger than χ_{it}, the sum of the first two terms of Equation (1) is larger than Equation (2); combined with the effect of speculative trading in the forward foreign exchange market on the optimal spot position, Equation (1) » Equation (2). Equation (2) is also the optimal position for the case that 1) the economy does not have a forward foreign exchange market or 2) the trader hedges only his price risk.

If traders do not hold a futures position or if they are not allowed to trade in the foreign

futures market, the traders except exporters do not need to hedge exchange rate risk. In this case, Equation (1) will become

$$S_{it} = \frac{\rho E_{it}(M_{it+1})\left[1 - A_i Cov_{it}(M_{it+1}, \xi_{it+1})\right] - C_{it}}{\lambda_i + \rho A_i Var_{it}(M_{it+1})} \tag{3}$$

for all *i*. If the trader does not trade in the foreign futures market but use the futures price to predict the future spot price, $E_{it}(M_{t+1})$ in Equation (3) will be a function of F_t. As Equation (3) < Equation (2) < Equation (1), allowing the trader to hedge his risks in the foreign futures market and the domestic forward exchange market will raise production level and supply of commodity in the domestic market. How much the spot position increases also depends on the correlation between commodity prices and exchange rates and the bias of the forward exchange market.

Unlike other trader types, exporters face exchange rate risk even though they do not trade in the foreign commodity futures market. If they choose to hedge their price risk in the offshore futures market, then they face more exchange rate risk. If they do not trade in the futures market but hedge the exchange rate risk of their export incomes, $Corr_{it}(\Phi_{t+1}, e_{t+1})$ and $Corr_{it}(M_{it+1}, \Phi_{t+1})$ disappear from Equation (1). As a result, the second term disappears and the last term is reduced; therefore, their optimal spot position becomes smaller than the optimal position given by Equation (1) but greater than the optimal position given by Equation (3).

Now let us consider a case in which the exporters precommit at time t to export the intermediate (final) commodity at time *t +1* at the preset export price P_{mt+1} (Q_{mt+1}). Practically, the preset price can be determined by the current export price and thus P_{mt+1} (Q_{mt+1}) are known at time t as assumed by Kofman and Viaene (1991) and Benninga and Oosterhof (2004). The exporters have no need to hedge price risk. The optimal positions will be

$$Y_{et} = \frac{\left[\rho P_{mt+1} f_t - P_t\right]}{2\beta} \tag{4}$$

for intermediate good exporters and

$$H_{et} = \frac{\left[\rho Q_{mt+1} f_t - Q_t\right]}{2\beta} \tag{5}$$

for final good exporters.

In the case that the final good is produced within a short period of time i.e. the processors can buy the intermediate commodity to produce the final good and sell the output to the market within the same period, they do not face any price risk and have no need to trade in the foreign commodity futures and forward foreign exchange markets. Then, their optimal spot position is

$$Y_{pt} = \frac{\rho g_{y_p} Q_t - P_t}{2\alpha} \tag{6}$$

where $g_{y_p} = \frac{\partial g(Y_{pt})}{\partial Y_{pt}}$.

The optimal futures position

The optimal futures position of the trader of type *i* is

$$\begin{aligned} Y_{it}^{f*} = & \frac{\left(\Phi_t - \rho E_{it}(\Phi_{t+1})\right)}{\rho A_i Var_{it}(\Phi_{t+1})\left((1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)} \\ & + \frac{(E_{it}(e_{t+1}) - f_t) Corr_{it}(\Phi_{t+1}, e_{t+1})}{A_i \left|\sqrt{Var_{it}(\Phi_{t+1}) Var_{it}(e_{t+1})}\right| (1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1}))} + Y_{it}^H \end{aligned} \tag{7}$$

for all *i*. The optimal futures position has 2 components: speculation and hedging. The first two terms are effects of speculation in the foreign commodity futures market and the forward foreign exchange market. Y_{it}^H is the hedging component:

$$Y_{it}^H = S_{it}^* \left|\sqrt{\frac{Var_{it}(M_{t+1})}{Var_{it}(\Phi_{t+1})}}\right| \frac{\{Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1}) Corr_{it}(\Phi_{t+1}, e_{t+1})\}}{(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1}))}$$

for all *i*. Y_{it}^H is a partial hedge of the expected output level. Whether the trader will short or long the contract depends on the expected gains in the foreign futures and forward foreign exchange markets, and his spot position.

If traders do not hedge their exchange rate risk, Z_{it}^{f*} is zero for all i . Then the second term disappears and so do some of the covariance terms in Equation (7). The optimal position reduces to

$$Y_{it}^{f*} = \frac{\Phi_t - \rho E_{it}(\Phi_{t+1})}{\rho A_i Var_{it}(\Phi_{t+1})} + S_{it}^* \left|\sqrt{\frac{Var_{it}(M_{t+1})}{Var_{it}(\Phi_{t+1})}}\right| Corr_{it}(M_{it+1}, \Phi_{t+1}) \tag{8}$$

If $Corr_{it}(\Phi_{t+1}, e_{t+1})Corr_{it}(M_{it+1}, \Phi_{t+1}) < Corr_{it}(M_{it+1}, e_{t+1})$, Y_{it}^{H} / S_{it}^{*} in Equation (8) is greater than in Equation (7) i.e. offshore hedging is more effective when they hedge both price and exchange rate risks. This is supported by empirical findings of Yun and Kim (2010).

The size of futures position may be affected by the type of commodity traded in the foreign futures market through the futures price and $Cov_{it}(M_{it+1}, \Phi_{t+1})$. For example, the covariance between the domestic price of final (intermediate) commodity and the foreign futures price of intermediate (final) commodity may be lower than the covariance between the domestic prices and the foreign futures price of the same commodity. The optimal spot and forward positions are also affected through the change in futures position.

The optimal forward position

The optimal forward position of the trader of type *i* is

$$Z_{it}^{f*} = \frac{E_{it}(e_{t+1}) - f_t}{A_i Var_{it}(e_{t+1})} + Y_{it}^{f*} \left| \sqrt{\frac{Var_{it}(\Phi_{t+1})}{Var_{it}(e_{t+1})}} \right| Corr_{it}(\Phi_{t+1}, e_{t+1}) - S_{it}^{*} \left| \sqrt{\frac{Var_{it}(M_{t+1})}{Var_{it}(e_{t+1})}} \right| Corr_{it}(M_{it+1}, e_{t+1}) \qquad (9)$$

Obviously, Z_{it}^{f*} is composed of two components: speculation (the first term) and hedging (the last two terms). The second term of Equation (9) is a partial hedge of the expected payment or receipts of foreign currency due to closing futures position at time *t+1* and its last term is a partial hedge of the expected future receipts from the spot market. If commodity prices and exchange rate are uncorrelated, the second term will become a full hedge, $Y_{it}^{f*} E_{it}(F_{t+1})$, and the last term will be zero for all traders except exporters.

In short, the optimal spot position is affected by the degree of risk aversion and thus the separation theorem is not applicable. Without hedging price risk in the foreign futures market or exchange rate risk in the domestic forward market, the spot commodity markets will have both lower demand and lower supply. For all traders, all optimal positions are affected by the type of commodity traded in the foreign futures market only through the futures prices and covariance between output prices and foreign futures prices. Note that by changing the subscript t to be *t-1*, we can get the optimal positions at time *t-1* for all traders.

2.4 Equilibrium price at maturity

The market-clearing conditions for the domestic markets of intermediate and final commodities in an exporting country at time *t* are

$$n_p Y^*_{pt} + n_e Y^*_{et} + n_s Y^*_{st} = n_f \left[f(X^*_{ft-1}) + \varepsilon_t \right] + n_s [Y^*_{st-1} + w^y_t] \tag{10}$$

and

$$n_e H^*_{et} + n_s H^*_{st} + H^*_{ct} = n_p \left[a Y^*_{pt-1} + v_t \right] + n_s \left[H^*_{st-1} + w^h_t \right], \tag{11}$$

respectively. H^*_{ct} is the demand for final goods of consumers at time t, assuming to be linear with the current domestic price i.e. $H^*_{ct} = c - dQ_t$. n_i denotes the number of the traders of type *i*. The left-hand side represents the demand in the spot market while the right-hand side represents the supply[8]. As domestic traders are small in the international market and the foreign futures and forward exchange markets, the futures price, export prices and spot and forward exchange rates are exogenous.

With both equilibrium conditions, the domestic equilibrium spot prices of intermediate and final commodities at time *t* are specified. The supply of commodities does not depend on the current domestic spot prices. It depends on the domestic spot prices of inputs, the foreign futures price and the forward exchange rate at time *t-1*, as well as the expected future prices and exchange rate perceived by producers and storage companies at time *t-1*. In contrast, the demand for commodities at time *t* depends on the current spot price, futures price and exchange rates. It also depends on the expected exchange rate and the expected prices of commodities sold at time *t+1* in the domestic commodity market, the world market and the foreign futures commodity market, perceived by traders at time *t*. So from Equation (10),

$$\sum_{i=p,e,s} \frac{n_{it}}{\chi_{it}} P_t = -n_f \left[f(X^*_{ft-1}) + \varepsilon_t \right] + n_p Y^*_{pt,-p} + n_e Y^*_{et,-p} + n_s (Y^*_{st,-p} - \left[Y^*_{st-1} + w^y_t \right])$$

where $Y^*_{it,-p} = S^*_{it} + \frac{P_{it}}{\chi_{it}}$, denoting the optimal position of the trader of type *i* excluding the effect of P_t. Consequently,

[8] For the importing country, Y_e and H_e are on the supply side.

$$P_t = \frac{-\sum_{i=f,s} n_i (S^*_{it-1} + \xi_{it}) + \sum_{i=p,e,s} n_i Y^*_{it,-p}}{\sum_{i=p,e,s} \left(n_{it} / \chi_{it} \right)} \tag{12}$$

From Equation (11), the equilibrium price of final goods in the domestic market is

$$\left(\sum_{i=e,s} \frac{n_{it}}{\chi_{it}} + d \right) Q_t = -n_p \left[g(Y^*_{pt-1}) + \nu_t \right] + n_e H^*_{et,-q} + H^*_{ct,-q} + n_s (H^*_{st,-q} - \left[H^*_{st-1} + w^h_t \right])$$

$$Q_t = \frac{-\sum_{i=p,s} n_i (S^*_{it-1} + \xi_{it}) + \sum_{i=c,e,s} n_i H^*_{it,-p}}{\sum_{i=e,s} \left(n_{it} / \chi_{it} \right) + d} \tag{13}$$

where $H^*_{it,-q}$ denotes the optimal position of the trader of type *i* excluding the effect of Q_t e.g. $H^*_{ct,-q} = c,$ and $H^*_{it,-q} = S^*_{it} + \frac{Q_{it}}{\chi_{it}}$ for *i*=*e* and *s*. Equation (12) and (13) supports the assumption given above that $Cov_{it}(M_{it+1}, \xi_{it+1}) < 0.$ Moreover, storage companies or the buffer stock's manager can raise the current spot price by buying more of the commodity at time *t*.

The domestic equilibrium prices depend on whether the forward exchange market is unbiased, which trader types hedge price and exchange rate risks, and whether exports are contracted in advance 1) if the forward exchange market is not unbiased, S^*_{it-1} is given by Equation (1), $Y^*_{it,-p}$ and $H^*_{it,-q}$ are

$$\frac{\left(\rho E_{it}(M_{it+1}) - \rho A_i E_{it}(M_{it+1}) Cov_{it}(M_{it+1}, \xi_{it+1}) \right)}{\chi_{it}}$$
$$+ \frac{\Phi_t - \rho E_{it}(\Phi_{t+1})}{\chi_{it}} \left| \sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}} \right| \frac{Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, e_{t+1})}{1 - Corr^2_{it}(\Phi_{t+1}, e_{t+1})}$$
$$+ \frac{\rho (E_{it}(e_{t+1}) - f_t)}{\chi_{it}} \left| \sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(e_{t+1})}} \right| \frac{Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1})}{1 - Corr^2_{it}(\Phi_{t+1}, e_{t+1})},$$

where

$$\chi_{it} = \lambda_i + \rho A_i Var_{it}(M_{it+1}) \{ 1 - \frac{Corr^2_{it}(M_{it+1}, \Phi_{t+1}) + Corr^2_{it}(M_{it+1}, e_{t+1})}{1 - Corr^2_{it}(\Phi_{t+1}, e_{t+1})} + \frac{2 Corr_{it}(M_{it+1}, e_{t+1}) Corr_{it}(\Phi_{t+1}, e_{t+1}) Corr_{it}(M_{it+1}, \Phi_{t+1})}{1 - Corr^2_{it}(\Phi_{t+1}, e_{t+1})} \}$$

2) if the forward exchange market is unbiased, traders do not hedge exchange rate risk, or $Corr_{it-1}(M_{it}, e_t) = 0$ and $Corr_{it-1}(\Phi_t, e_t) = 0$ for all i, S^*_{it-1} is given by Equation (2), $Y^*_{it,-p}$ and

$H^*_{it,-q}$ are

$$\frac{\rho E_{it}(M_{it+1})(1-A_i Cov_{it}(M_{it+1},\xi_{it+1})}{\lambda_i+\rho A_i Var_{it}(M_{it+1})\left[1-Corr^2_{it}(M_{it+1},\Phi_{t+1})\right]}+\frac{\left[\Phi_t-\rho E_{it}(\Phi_{t+1})\right]Corr_{it}(M_{it+1},\Phi_{t+1})}{\lambda_i+\rho A_i Var_{it}(M_{it+1})\left[1-Corr^2_{it}(M_{it+1},\Phi_{t+1})\right]}\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}}\right|,$$

3) if traders do not hold a futures position or if they are not allowed to trade in the foreign futures market, S^*_{it-1} for the traders except exporters is given by Equation (3), $Y^*_{it,-p}$ and $H^*_{it,-q}$ are

$$\frac{\left[\rho E_{it}(M_{it+1})-\rho A_i E_{it}(M_{it+1})Cov_{it}(M_{it+1},\xi_{t+1})\right]}{\lambda_i+\rho A_i Var_{it}(M_{it+1})},$$

4) if exports are contracted in advance,

$$Y^*_{et,-p}=\frac{\rho P_{mt+1} f_t}{2\beta} \text{ and } H_{et,-q}=\frac{\rho Q_{mt+1} f_t}{2\beta}$$

Thus, Equation (12) can be rewritten as a general form:

$$P_t = f(r_{t-1}, P_{t-1}, \Phi_{t-1}, \Phi_t, f_{t-1}, f_t, \Lambda_{it-1}, \Lambda_{jt}, \Omega_{it-1}, \Omega_{jt}) + \eta_{pt} \tag{14}$$

where *i=f,s* and *j=p,e,s*. Λ_{it} and Λ_{jt+1} are sets of the expected future price and exchange rate perceived by the trader of type *i* at time *t* e.g. $E_{it}(P_{t+1}), E_{it}(\Phi_{t+1})$ and $E_{it}(e_{t+1})$, and the expected future price and exchange rate perceived by the trader of type *j* at time *t+1* e.g. $E_{pt+1}(Q_{t+2})$, $E_{sy,t+1}(P_{t+2})$, $E_{ey,t+1}(P_{mt+2}e_{t+2})$, $E_{jt+1}(\Phi_{t+2})$ and $E_{jt}(e_{t+2})$, respectively. Ω_{it} and Ω_{jt+1} are sets of expected variances and correlations of future prices and exchange rates, perceived by the trader of type *i* at time *t* and the trader of type *j* at time *t+1*, respectively. η_{pt} = - $(n_f \varepsilon_{t+1} + n_{sy} w^y_{t+1})$; it has a mean value of 0 and a constant variance.

Likewise, Equation (13) can be rewritten as a general function:

$$Q_t = f(P_{t-1}, Q_{t-1}, \Phi_{t-1}, \Phi_t, f_{t-1}, f_t, \Lambda_{kt-1}, \Lambda_{mt}, \Omega_{kt-1}, \Omega_{mt}) + \eta_{qt} \tag{15}$$

where *k=p,s* and *m=e,s*. $\Lambda_{kt} = \{E_{kt}(Q_{t+1}), E_{kt}(\Phi_{t+1}), E_{kt}(e_{t+1})\}$ and $\Lambda_{mt} = \{E_{st+1}(Q_{t+2}), E_{et+1}(Q_{mt+2}e_{t+2}), E_{mt+1}(\Phi_{t+2}), E_{mt}(e_{t+2})\}$. Ω_{kt} and Ω_{mt+1} are sets of expected variances and covariances of final goods prices, the futures price and the exchange rate, perceived by the trader of

type *k* at time *t* and the trader of type *m* at time *t+1*, respectively. $\eta_{qt} = -(n_p v_{t+1} + n_{sh} w^h_{t+1})$; it has a mean value of 0 and a constant variance.

If the forward market is unbiased, all traders do not hedge exchange rate risk, or $Corr_{it}(M_{it+1}, e_{t+1}) = 0$ and $Corr_{it}(\Phi_{t+1}, e_{t+1}) = 0$ for all *i*, then there is no direct effect of the forward rate, the expected value and variance of the exchange rate on domestic commodity prices, but via the world spot prices and foreign futures prices of commodities which are converted into the unit of domestic currency.

As can be seen from Equation (1) and (2), the optimal spot position can be affected by $Var_{it}(\Phi_{t+1})$ or $Var_{it}(e_{t+1})$. Thus the equilibrium prices are also affected by exchange rate volatility. However, whether the effect is positive or negative depends on (i) which traders hedge their price and exchange rate risks, (ii) the sign of $Corr_{it}(\Phi_{t+1}, e_{t+1})$ and (iii) the exchange rate elasticity of supply and demand. This is supported by the conclusion of Chu and Morrison (1984) that one of the dominant sources of commodity price variability was the volatility of exchange rates. Appendix B shows that an increase in the expected value of world prices and a decrease in their volatilities will raise export volume. The increase in export volume causes the domestic demand for commodities, which are the input, to increase; therefore, the domestic prices of commodities increase as can be seen from Equation (12) and (13). This finding explains what happened to Thai rice and sugar markets in 2008. In the case that the country is the importer of commodities, if the current world price increases, import volume will decrease; it lowers the domestic supply of commodities and thus increases the domestic price. This finding can explain the recent increase in fuel prices in many countries. So the world price and domestic prices are positively correlated in both exporting and importing countries.

3. Empirical studies

Based on the theoretical result in the previous section, trading in the foreign commodity futures market and the forward exchange market affect the domestic spot prices through the speculative component of traders' optimal spot holding. In this section, the determinants of spot

prices at maturity are investigated empirically. The aim is to find whether domestic spot prices are affected by the foreign futures price and the spot and forward exchange rates through trading in the offshore commodity futures market and the currency market. This paper applies the Thai rice and rubber markets as case studies. As Thailand only exports final goods of rice and rubber (milled rice and smoked rubber sheet (RSS)), $Y^*_{et+1} = 0$ and domestic prices are not affected by the world price of the intermediate goods. The export prices of milled rice and RSS3 in this empirical study are Thai F.O.B. prices.

In the case of Thai rubber, the first futures contract of smoked rubber sheets traded in the AFET matured in September 2004. The domestic prices of intermediate and final goods applied in this study are the prices of natural rubber sheets and smoked rubber sheets no.3 (RSS3) which have been recorded by the Thai Office of the Rubber Replanting Aid Fund since 1998, so the analysis covers the period from January 1998 to May 2004. Rubber tree takes many years to grow, so the production cost is mainly fixed and the cost of seed is relatively small and so can be ignored ($r_t \approx 0$). The futures price of RSS3 is the price of a futures contract traded at SICOM. There are 12 maturity months i.e. 12 calendar months. The last trading day is the last working day of the maturity month. For this case study, spot and 1-month forward exchange rates are in THB/SGD. So there are a total of 77 monthly observations employed.

In the case of Thai rice, the futures contract maturing in November 2004 was the first contract of milled rice traded in the AFET. The foreign futures price applied here is the U.S. rough rice futures price. The CBOT trades rough rice futures contracts with 6 maturity months: January, March, May, July, September, and November. The last trading day is the mid of the maturity month. To exclude the effect of exchange rate regime switching on July 2, 1997, we use the mid-month data within the period from July 1997 to June 2004. The domestic prices are the Thai rough rice and milled rice prices in maturity months. The primary commodity of rough rice is rough rice, so $r_t = P_t$. The spot and 2-month forward exchange rates are in THB/USD. In total, there are 46 observations for this case.

To simplify the solution and to allow the model to be easily estimated, we assume that, for each agent, conditional variances and covariances of prices and production shocks are constant

through time[9]. Before estimating the system of equations, the KPSS unit root test is applied to test the stationarity of the variables. The null hypothesis of the KPSS test is that each series is stationary. As shown in Table l, all variables are stationary at the 0.01 significance level. So this assumption is valid.

[Insert Table 1 about here]

[Insert Table 2 about here]

Table 2 supports the correlation conditions assumed in the theoretical framework. It also shows that the THB/SGD exchange rate is significantly correlated with the world price of RSS3 (in domestic currency) at the 0.1 significance level and that all rice prices (in domestic currency) are not significantly correlated with the THB/USD exchange rate i.e. $Corr_{it}(M_{it+1}, e_{t+1}) = 0$ and $Corr_{it}(\Phi_{t+1}, e_{t+1})$=0. This finding is different from the findings of Kofman and Viaene (1991) and Gilbert (1991); it may be due to Thailand moving from a fixed exchange rate system to a managed-float system in 1997. Thus, the optimal positions of traders and equilibrium prices in the Thai rubber market and the Thai rice market are different. That is, if the forward exchange market is biased, we expect to find a significant effect of exchange rates on the domestic price of RSS3 via currency trading and no significant effect on the domestic prices of rice. Otherwise, there should be no effect of exchange rates via currency hedging, but via offshore hedging, in both markets. As shown in the theoretical framework above and the proposition of Kawai and Zilcha (1986) as well as Kofman and Viaene (1991), to be persuaded to hold forward contracts, risk-averse traders have to receive a risk premium to compensate for the uncertainty regarding the expected future spot rate. In other words, the forward foreign exchange market is biased i.e. $E_{t-1}(e_t) \neq f_{t-1}$.

[9]This assumption can be justified by a rational expectations paradigm. That is, the conditional distribution for each agent comes from distributions of production shocks and storage uncertainty as well as the market-clearing condition determining P_{t+1} and Q_{t+1} above. Agents know that the domestic commodity spot price is a linear function of production and storage uncertainty. These variables have constant variance-covariance matrices through time so do the distributions Ω_{it} and Ω_{jt}. As Q_{mt+1}, F_{t+1} and e_{t+1} are exogenous, the covariance and variances of these variables are given and assumed to be constant. If the mean values of market prices are nonnegative, the rational agents' expected values of future prices will also be nonnegative.

[Insert Table 3 about here]

The heteroscedasticity-robusted standard error ordinary least square regression of $e_t = \phi_0 + \phi_1 f_{t-1} + \omega_t$ in Table 3 shows that the forward exchange markets are biased and the current exchange rate depends on the previous forward rate. Trading in the forward exchange market can affect the optimal position of exporters in the rubber market i.e. the optimal spot position is given by Equation (1) if exporters choose to hedge their exchange rate risk. The optimal position of other traders in the rubber market and all traders in the rice market are express in Equation (2) if they hedge their price risk. As a result, the forward exchange rate is expected to have a significant effect on Thai rubber prices. Whether the intermediate and final commodity prices are affected by foreign futures prices depends on who trade in the foreign commodity futures market.

Consequently, we estimate Equation (14) and (15) for both markets by assuming that all the terms in a coefficient (such as the degree of risk aversion, the number of traders and variances and covariances of prices) are constant. From equilibrium prices derived in the previous section, the current domestic spot price relates to the previous price. Due to data limitation and to simplify the model, we assume that the commodity prices follow AR(1) process. For example, $E_{t-1}(Q_{mt}e_t) = \delta_0 + \delta_1 Q_{mt-1}e_{t-1}$ and $E_{t-1}(\Phi_t) = E_{t-1}(F_t e_t) = \gamma_0 + \gamma_1 F_{t-1}e_{t-1}$. Though more lags may be included to correct autocorrelation problem. Based on the test result above, the expected future exchange rate is a function of the current forward exchange rate, $E_{t-1}(e_t) = \phi_0 + \phi_1 f_{t-1}$.

Equation (14) and (15) can be rewritten as

$$P_t = a_0 + a_1 Q_t + a_2 P_{t-1} + a_3 F_{t-1}e_{t-1} + a_4 F_t e_t + a_5 f_{t-1} + a_6 f_t + \eta_{pt}. \quad (16)$$

$$Q_t = b_0 + b_1 Q_{mt}e_t + b_2 P_{t-1} + b_3 F_{t-1}e_{t-1} + b_4 F_t e_t + b_5 f_{t-1} + b_6 f_t + b_7 Q_{t-1} + \eta_{qt}. \quad (17)$$

a_0 and b_0 are the sums of the constant terms in the expectation functions, so they can be either positive or negative. Based on the theoretical result, a_1 and b_1 are expected be positive as Q_t and $Q_{mt}e_t$ are used to forecast the future prices of outputs of processors and exporters, respectively. P_{t-1} is the input cost for farmers and storage companies selling the intermediate commodity at time t and Q_{t-1} is

the input cost for storage companies selling the final commodity at time *t*; both are also used to predict the future prices at time *t*. Therefore, a_2 and b_7 can be positive, negative or insignificant. P_{t-1} is also the input cost of processors, so b_2 is expected to be positive. If producers hedge their price risks, the estimator of a_3 is expected to be significant. The estimators of both a_4 and b_3 should be significant if processors hedge their price risk. If the companies storing intermediate commodity (final commodity) trade in the futures market, both a_3 and a_4 (b_3 and b_4) will be non-zero. In addition, a non-zero value of b_4 will indicate the effects of the foreign futures price and exchange rate on the domestic price of final commodity via exporters' foreign futures trading. If the exporters in the rubber market also trade in the forward exchange market, then b_6 of (17) is expected to be positive if $Corr_{it}(M_{it+1}, e_{t+1}) > Corr_{it}(M_{it+1}, \Phi_{t+1})Corr_{it}(\Phi_{t+1}, e_{t+1})$. According to correlations between exchange rates and commodity prices reported in Table 2, estimates of a_5, a_6 and b_5 are expected to be insignificant. The sign of coefficients of the foreign futures prices (in domestic currency) and the forward rates depend on (i) the value of γ_1 and ϕ_1, (ii) who trades in the foreign futures commodity and forward exchange markets and (iii) whether the trader holds long or short positions in the markets.

[Insert Table 4 about here]

Applying the two-stage-least-squares estimation approach, the estimation results in Table 4 and 5 show that commodity prices are affected by spot and forward exchange rates through exports and offshore hedging. For the Thai rubber market, removing insignificant variables and correcting for any multicollinearity[10] or autocorrelation problem by adding more lags of domestic and world prices of RSS3 yields model RS4. The estimates of a_1 and b_1 are positive as expected. In addition, the estimates of a_5, a_6 and b_5 are insignificant while the estimate of b_6 is positive. This implies that exports hedge their price and exchange rate risks and that the forward exchange rate can affect the

[10] P_{t-1} and Q_{t-1} are highly correlated as shown in Table 2.

final commodity price through the optimal spot position of exporters only. The significance of the estimates of a_4, b_3 and b_4 may indicate that all traders in the final commodity market hedge their price risks in the SICOM or use the futures price to predict the future spot price. Unlike the smoked rubber sheet market, producers and storage companies in the natural rubber sheet market do not hedge their risks, but use the futures price to predict the future spot price.

[Insert Table 5 about here]

For the Thai rice market, removing the insignificant coefficients in Equation (17) we obtain models R2-R4. R2 does not have both P_{t-1} and Q_{t-1} which are highly correlated while R3 has the first lag of intermediate goods price and R4 has the first lag of final goods price. R4 is chosen because all coefficients are significant, the model does not have heteroscedasticity, autocorrelation and mis-specification problems, and it has the highest explanatory power. As expected, the estimates of a_1 and b_1 are positive. This indicates that processors and exporters of the final commodity use the current prices of that final commodity to predict the future price in the domestic and international market. Due to $Corr_{it}(M_{it+1}, e_{t+1})$ and $Corr_{it}(\Phi_{t+1}, e_{t+1})$ are insignificantly different from zero, estimates of a_5, a_6, b_5 and b_6 are insignificant as suggested by the theoretical framework. The significance of the estimate of b_4 indicates that the exporters of the final commodity hedge their price risk in the CBOT or use the futures price to predict the future spot price. The model R4 shows that exchange rates have an effect on domestic commodity prices through offshore hedging and international trade by rice exporters even though commodity prices (in domestic currency) and exchange rates are uncorrelated.

[Insert Figure 2 about here]

The models have remarkably high explanatory power. The graphs of fitted and actual values in Figure 2 show that the models fit the data very well. $\hat{\eta}_{pt}$ and $\hat{\eta}_{qt}$ are the estimated residual of which statistics are summarised in Table 6. The statistics shows that the estimated residuals are

stationary and normally distributed with mean values equal to 0 and a constant variance as assumed in the theoretical framework.

[Insert Table 6 about here]

In short, this empirical analysis shows that the inefficiency of the forward exchange market and the correlation between the exchange rate and the world price of smoked rubber sheets allow the forward exchange rate to affect the domestic rubber prices. It also shows that producers in both markets do not hedge their price risk while exporters hedge their price and exchange rate risks in both markets. Rubber storage companies appear to hedge their price risk while rice storage companies do not; this may be because rough rice is stored by a government agency through a price guarantee program while there is no such program for rubber.

4. Conclusion

In conclusion, the framework is developed to find the optimal offshore trading strategy and determine how it affects the optimal spot commodity and forward foreign exchange positions. The framework expands the models of Kawai and Zilcha (1986) to explain trading by other trader types. It relaxes the assumptions of Kawai and Zilcha (1986) and Kofman and Viaene (1991) by allowing both intermediate and final goods to be traded in the international and future markets. As suggested by Kawai and Zilcha (1986), this framework allows exporters to face export shocks, factor costs and random export prices. Like other frameworks, traders are assumed to close all of their futures position due to high delivery and transaction costs. Then, equilibrium prices at maturity in the domestic commodity markets are derived to illustrate how offshore trading allows exchange rates to affect commodity prices in a country without its own commodity futures markets.

Applying a two-period mean-variance approach, this framework shows that the changes in the futures price and the exchange rate as well as and volatilities can affect the spot positions and domestic prices of internationally tradable commodities in many cases. Firstly, traders hedge their

price risk in the foreign commodity futures market and exchange rate risk in the biased forward exchange markets and the commodity prices are correlated with the exchange rate. Secondly, exporters (importers) and traders hedging their price risk in the foreign futures market are interested in the profits dominated in domestic currency; the effects exist even though the forward exchange rate is an unbiased forecast of the future exchange rate or commodity prices and exchange rates are uncorrelated. Thirdly, traders use the foreign futures price as information in predicting future commodity prices.

Like Kawai and Zilcha (1986), we find that without the correlation between commodity prices and exchange rates, the trader's optimal position in the forward exchange market is full hedging of his expected foreign currency payments and receipts and speculation in the domestic currency market. The optimal futures position is a partial hedge of the spot position, speculation in the futures market and the effect of speculation in the forward market. We also find that the separation theorem does not apply to the optimal spot position here. The spot position will be greater when the traders hedge their risks. Whether offshore hedging of all traders will be more effective when they hedge both price and currency risks depends on the correlations of commodity prices with the exchange rate. Increases in variances of prices and exchange rates can decrease traders' optimal spot and futures positions while a rise in the correlation between the domestic spot price and the foreign futures price can increase their optimal positions. Increases in the difference between the expected spot exchange rate and the forward exchange rate, exchange rate volatility, and correlations of exchange rates and domestic commodity prices can either increase or decrease the commodity spot price; this depends on which traders hedge their exchange rate risk and whether the effects of these changes on the supply is greater than the effects on the demand in the markets.

The empirical results also support the theoretical conclusion. We find that the prices of Thai rice and rubber sheets are affected by exchange rates though exports and offshore hedging even though rice prices (in domestic currency) and the exchange rate are not correlated. Offshore hedging by different trader types leads to different impacts of foreign futures prices and foreign exchange rates on domestic commodity prices. With the bias of the forward exchange market and the significant

correlation between the exchange rate and the world price of RSS no.3, we find the effect of the forward exchange rate on the domestic price of smoked rubber sheets. The model also indicates that some traders hedge their price risk in the foreign futures market and some do not hedge their risk.

Further research could test the prices of more commodities in different countries and calculate the optimal hedging ratios based on the optimal strategy found in this paper. Within the context of an international financial portfolio, Schmittmann (2010) found the optimal currency hedging ratios for investing in single-country portfolios and a multi-country portfolio and documented that both exchange rate volatility and the correlations of exchange rates with bond and equity returns could increase risk exposure to investors. So further theoretical research could expand the framework in this paper to find the optimal hedging ratio in the foreign futures equity market for investors holding shares of the firm which is listed on the stock exchange of a small country without its own futures market and which has futures contracts traded in the foreign futures market. Further research could also compare the optimal strategy, price volatility and trader's welfare before and after the existence of a domestic commodity futures market. Any finding from such a comparison would guide policy makers as to whether the country should have a domestic commodity futures market. Also, empirical work could be done using recent commodity prices to investigate how prices and trader behaviour change when a domestic commodity future market becomes available.

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Appendix A

The profit of the traders can be rewritten in a general form as

$$\Pi_i = Y_{it}^f \Phi_t - C_{it} S_{it} - \lambda_i S_{it}^2 + \rho\{M_{it+1}(S_{it} + \xi_{it+1}) - Y_{it}^f \Phi_{t+1} + (e_{t+1} - f_t) Z_{it}^f\}.$$

He choose S_{it}, Y_{it}^f and Z_{it}^f at time by maximising his expected utility

$$V_i = \underset{Y_{it}^f,\, Y_{it}, Z_{it}^f}{Max} \{Y_{it}^f \Phi_t - C_{it} S_{it} - \frac{\lambda_i}{2} S_{it}^2 + \rho[E_{it}(\Pi_{it+1}^*) - \frac{A_i}{2} Var_{it}(\Pi_{it+1}^*)]\}.$$

where the expected future profit is

$$E_{it}(\Pi_{it+1}^*) = E_{it}(M_{t+1}) S_{it} + E_{it}(M_{it+1}\xi_{it+1}) - Y_{it}^f E_{it}(\Phi_{t+1}) + \left[E_{it}(e_{t+1}) - f_t\right] Z_{it}^f$$

and the variance of his expected future profit is

$$Var_{it}(\Pi^*_{it+1}) = Var_{it}(M_{it+1})S^2_{it} + Var_{it}(M_{it+1}\xi_{it+1}) + Var_{it}(\Phi_{t+1})Y^{f\,2}_{it} + Z^{f\,2}_{it}Var_{it}(e_{t+1})$$
$$+2S_{it}Cov_{it}(M_{t+1}, M_{t+1}\xi_{it+1}) - 2S_{it}\left(Y^f_{it}Cov_{it}(M_{it+1}, \Phi_{t+1}) - Z^f_{it}Cov_{it}(M_{it+1}, e_{t+1})\right)$$
$$-2Y^f_{it}Cov_{it}(M_{it+1}\xi_{it+1}, \Phi_{t+1}) + 2Z^f_{it}Cov_{it}(M_{it+1}\xi_{it+1}, e_{t+1}) - 2Y^f_{it}Z^f_{it}Cov_{it}(\Phi_{t+1}, e_{t+1})$$

where $Cov_{it}(\xi_{it+1}, e_{t+1}), Cov_{it}(M_{it+1}\xi_{it+1}, \Phi_{t+1})$ and $Cov_{it}(M_{it+1}\xi_{it+1}, e_{t+1})$ are equal to 0.

His FOC with respect to S_{it} is

$$\frac{\partial V_i}{\partial S_{it}} = -C_t - \lambda_i S_{it} + \rho[E_{it}(M_{it+1}) - A_i\{S_{it}Var_{it}(M_{it+1}) + Cov_{it}(M_{it+1}\xi_{it+1}, M_{it+1})$$
$$-Y^f_{it}Cov_{it}(M_{it+1}, \Phi_{t+1}) + Z^f_{it}Cov_{it}(M_{it+1}, e_{t+1})\}] = 0$$

The FOCs with respect to Y^f_{it} and Z^f_{it} are

$$\frac{\partial V_i}{\partial Y^f_{ft}} = \Phi_t - \rho E_{it}(\Phi_{t+1}) - \rho A_i\{Y^f_{it}Var_{it}(\Phi_{t+1}) - S_{it}Cov_{it}(M_{it+1}, \Phi_{t+1}) - Z^f_{it}Cov_{it}(\Phi_{t+1}, e_{t+1})\} = 0$$

$$\frac{\partial V_i}{\partial Z^f_{it}} = \rho\left(E_{it}(e_{t+1}) - f_t\right) - \rho A_i\{Z^f_{it}Var_{it}(e_{t+1}) - Y^f_{it}Cov_{it}(\Phi_{t+1}, e_{t+1}) + S_{it}Cov_{it}(M_{it+1}, e_{t+1})\} = 0$$

Appendix B

The effect of changes in price and exchange rate volatilities are as follows.

$$\frac{\partial S^*_{it}}{\partial Var_{it}(M_{it+1})} = -S^*_{it}\frac{\chi_{it} - 2\lambda_{it}}{2\chi_{it}\left|\sqrt{Var^3_{it}(M_{it+1})}\right|} < 0$$

$$\frac{\partial S^*_{it}}{\partial Var_{it}(\Phi_{t+1})} = \frac{\Phi_t - \rho E_{it}(\Phi_{t+1})}{2\chi_{it}}\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var^3_{it}(\Phi_{t+1})}}\right|\frac{Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(\Phi_{t+1}, e_{t+1})Corr_{it}(M_{it+1}, e_{t+1})}{1 - Corr^2_{it}(\Phi_{t+1}, e_{t+1})}$$
$$-\frac{\partial S^*}{\partial Corr_{it}(\Phi_{t+1}, e_{t+1})}\frac{Corr_{it}(\Phi_{t+1}, e_{t+1})}{2Var_{it}(e_{t+1})}$$

where

$$\frac{\partial S^*_{it}}{\partial Corr_{it}(\Phi_{it+1}, e_{t+1})} = -\frac{\left(\Phi_t - \rho E_{it}(\Phi_{t+1})\right)\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}}\right|Corr_{it}(M_{t+1}, e_{t+1})}{\chi_{it}}$$
$$+\frac{\rho(E_{it}(e_{t+1}) - f_t)\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(e_{t+1})}}\right|Corr_{it}(M_{t+1}, \Phi_{t+1})}{\chi_{it}}$$
$$+2\frac{S^*_{it}}{\chi_{it}}(\lambda_i Corr(\Phi_{t+1}, e_{t+1}) + \rho A_i Var_{it}(M_{it+1})(Corr_{it}(\Phi_{t+1}, e_{t+1}) - Corr_{it}(M_{it+1}, \Phi_{t+1})Corr_{it}(M_{it+1}, e_{t+1})))$$

of which the sign is ambiguous as $Corr_{it}(\Phi_{t+1}, e_{t+1})$ can be positive, negative or zero. Thus, the effect of the volatility of the foreign futures price on the optimal spot position is ambiguous.

$$\frac{\partial S_{it}^*}{\partial Var_{it}(e_{t+1})} = -\frac{\rho(E_{it}(e_{t+1}) - f_t)\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}^3(e_{t+1})}}\right|}{2\chi_{it}\left(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)}\left(Corr_{it}(\Phi_{t+1}, e_{t+1})Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1})\right)$$
$$+ \frac{\partial S^*}{\partial Corr_{it}(\Phi_{t+1}, e_{t+1})}\frac{\partial Corr_{it}(\Phi_{t+1}, e_{t+1})}{\partial Var_{it}(e_{t+1})}$$

Its sign is ambiguous because the sign of the second term is ambiguous as

$$\frac{\partial Corr_{it}(\Phi_{t+1}, e_{t+1})}{\partial Var_{it}(e_{t+1})} = \frac{E_{it}(F_{t+1})}{\sqrt{Var_{it}(F_{t+1}e_{t+1})Var_{it}(e_{t+1})}} - Corr_{it}(\Phi_{t+1}, e_{t+1})\frac{Var_{it}(F_{t+1}e_{t+1}) + Var(F_{t+1})Var(e_{t+1})}{2Var_{it}(F_{t+1}e_{t+1})Var_{it}(e_{t+1})}$$

which can be positive, negative or zero.

$$\frac{\partial S_{it}^*}{\partial Corr_{it}(M_{it+1}, e_{t+1})} = -\frac{\left(\Phi_t - \rho E_{it}(\Phi_{t+1})\right)\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}}\right| Corr_{it}(\Phi_{t+1}, e_{t+1}) + \rho(E_{it}(e_{t+1}) - f_t)\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(e_{t+1})}}\right|}{\chi_{it}\left(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)}$$
$$-2S_{it}^*\rho A_i Var_{it}(M_{it+1})\frac{(Corr_{it}(\Phi_{t+1}, e_{t+1})Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1}))}{\chi_{it}\left(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)^2}$$
$$< 0$$

and

$$\frac{\partial S_{it}^*}{\partial Corr_{it}(M_{it+1}, \Phi_{t+1})} = \frac{\left|\sqrt{\frac{Var_{it}(M_{it+1})}{Var_{it}(\Phi_{t+1})}}\right|\left(\Phi_t - \rho E_{it}(\Phi_{t+1}) + \rho(E_{it}(e_{t+1}) - f_t)Corr_{it}(\Phi_{t+1}, e_{t+1})\right)}{\chi_{it}\left(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)}$$
$$+2S_{it}^*\rho A_i Var_{it}(M_{it+1})\frac{(Corr_{it}(M_{it+1}, \Phi_{t+1}) - Corr_{it}(M_{it+1}, e_{t+1})Corr_{it}(\Phi_{t+1}, e_{t+1}))}{\chi_{it}\left(1 - Corr_{it}^2(\Phi_{t+1}, e_{t+1})\right)}$$
$$> 0$$

if the effect of the expected gains of trading in the foreign futures market and the forward exchange market on the optimal spot position is non-negative.

Appendix C

1. $Var(AB) = E\left[AB - E(AB)\right]^2$

where A and B are random variables. Define $X = A - E(A)$ and $Y = B - E(B)$. Then, $A = X + E(A)$ and $B = Y + E(B)$. Therefore,

$$Var(AB) = E[XY + XE(B) + YE(A) - Cov(A,B)]^2$$
$$= E[X^2Y^2 + 2X^2YE(B) + 2XY^2E(A) - 2XYCov(A,B) + X^2E(B)^2 + Y^2E(A)^2$$
$$+2XYE(A)E(B) - 2XE(B)Cov(A,B) - 2YE(A)Cov(A,B) + Cov^2(A,B)]$$

As $E(X^2Y^2) = Var(A)Var(B) + 2Cov^2(A,B), E(X^2YE(B)) = 0, E(XY^2E(A)) = 0,$

$$Var(AB) = Var(A)Var(B) + Cov^2(A,B) + E(B)^2Var(A) + E(A)^2Var(B) + 2Cov(A,B)E(A)E(B)$$

For example,

$$Var_{it}(F_{t+1}e_{t+1}) = Var(F_{t+1})Var(e_{t+1}) + Cov^2(F_{t+1}, e_{t+1})$$
$$+E(e_{t+1})^2Var(F_{t+1}) + E(F_{t+1})^2Var(e_{t+1}) + 2Cov(F_{t+1}, e_{t+1})E(F_{t+1})E(e_{t+1})$$

2. $Cov(AB, CD) = E[AB - E(AB)][CD - E(CD)]$

Suppose $A = \Delta A + E(A)$, $B = \Delta B + E(B)$, $C = \Delta C + E(C)$, $D = \Delta D + E(D)$

$Cov(AB, CD) = E[\Delta A\Delta B + \Delta AE(B) + \Delta BE(A) - Cov(A, B)] \cdot [\Delta C\Delta D + \Delta CE(D) + \Delta DE(C) - Cov(C, D)]$

$= E[\Delta A\Delta B\Delta C\Delta D + \Delta A\Delta B\Delta CE(D) + \Delta A\Delta B\Delta DE(C) - \Delta A\Delta BCov(C, D)$

$+ \Delta A\Delta CE(B)E(D) + \Delta A\Delta DE(B)E(C) - \Delta AE(B)Cov(C, D) + \Delta A\Delta C\Delta DE(B)$

$+ \Delta B\Delta C\Delta DE(A) + \Delta B\Delta CE(A)E(D) + \Delta B\Delta DE(A)E(C) - \Delta BE(A)Cov(C, D)$

$- \Delta C\Delta DCov(A, B) - \Delta CE(D)Cov(A, B) - \Delta DE(C)Cov(A, B) + Cov(A, B)Cov(C, D)]$

With $E[\Delta A\Delta B\Delta C\Delta D] = Cov(A, B)Cov(C, D) + Cov(A, C)Cov(B, D) + Cov(A, D)Cov(C, B)$,

$E[\Delta A] = 0$, $E[\Delta B] = 0$, $E[\Delta C] = 0$, $E[\Delta D] = 0$, $E[\Delta A\Delta B\Delta CE(D)] = 0$, $E[\Delta A\Delta B\Delta DE(C)] = 0$, $E[\Delta A\Delta C\Delta DE(B)] = 0$ and $E[\Delta B\Delta C\Delta DE(A)] = 0$, we obtain

Cov(AB, CD) = Cov(A, C)Cov(B, D) + Cov(A, D)Cov(B, C)+Cov(A, C)E(B)E(D)

+ Cov(A, D)E(B)E(C)+Cov(B, C)E(A)E(D)+Cov(B, D)E(A)E(C)

and Cov(AB, C) = Cov(A, C)E(B) + Cov(B, C)E(A).

For example,

$$Corr_{it}(F_{t+1}e_{t+1}, e_{t+1}) = \frac{Cov_{it}(F_{t+1}e_{t+1}, e_{t+1})}{\sqrt{Var_{it}(F_{t+1}e_{t+1})Var_{it}(e_{t+1})}} = \frac{E_{it}(F_{t+1})Var_{it}(e_{t+1}) + E_{it}(e_{t+1})Cov_{it}(F_{t+1}, e_{t+1})}{\sqrt{Var_{it}(F_{t+1}e_{t+1})Var_{it}(e_{t+1})}}$$
$$= \frac{E_{it}(F_{t+1})Var_{it}(e_{t+1})}{\sqrt{Var_{it}(F_{t+1}e_{t+1})Var_{it}(e_{t+1})}} = E_{it}(F_{t+1})\sqrt{\frac{Var_{it}(e_{t+1})}{Var_{it}(F_{t+1}e_{t+1})}}$$

if $Cov_{it}(F_{t+1}, e_{t+1}) = 0$.

Table 1: the KPSS unit root test of variables

Commodity	P_t	Q_t	Q_{mt}	$Q_{mt}e_t$	F_t	F_te_t	e_t	f_t
Rubber	0.154	0.161	0.148	0.166	0.146	0.151	0.097	0.093
Rice	0.181	0.175	0.191	0.184	0.186	0.177	0.115	0.108

Note: The critical value at the 0.01 significance level is 0.216

Table 2: Correlations among commodity prices and exchange rates

	Rubber					Rice			
	P_t	Q_t	$Q_{mt}e_t$	F_te_t		P_t	Q_t	$Q_{mt}e_t$	F_te_t
Q_t	0.993 (75.162)				Q_t	0.911 (14.016)			
$Q_{mt}e_t$	0.947 (25.480)	0.952 (26.952)			$Q_{mt}e_t$	0.890 (12.323)	0.985 35.965		
F_te_t	0.975 (37.794)	0.980 (43.151)	0.972 (35.820)		F_te_t	0.721 (6.588)	0.742 (7.009)	0.786 (8.028)	
e_t	0.132 (1.150)	0.122 (1.067)	0.202 (1.788)	0.140 (1.223)	e_t	−0.151 (−0.966)	0.008 (0.048)	0.010 (0.064)	−0.027 (−0.173)

Note: The values in parentheses are t-statistics

Table 3: Efficient market hypothesis testing of forward exchange markets

Currency Market	THB/SGD	THB/USD
Variable	Coefficient (S.E.)	Coefficient (S.E.)
Constant	2.92 (1.36)*	22.36 (7.99)**
f_{t-1}	0.88 (0.06)**	0.46 (0.20)*
Adj-R^2	84.80%	24.60%
AR Test: F-stat (Prob.)	2.19 (0.13)	0.39 (0.68)

Note: ** and * denote the significance of coefficients at 1% and 5% significance levels, respectively

Table 4: Regression results of the Thai rubber market

Equation		Model RS1	Model RS2	Model RS3	Model RS4
P_t	Constant	-10.50 (2.30)**	-11.84 (2.50)	-9.76 (2.54)**	-0.44 (0.74)
	Q_t	2.16 (0.64)**	0.63 (0.12)**	1.67 (0.62)**	0.57 (0.14)**
	P_{t-1}	-0.27 (0.16) †	0.05 (0.09)	0.27 (0.08)**	0.68 (0.14)**
	$F_{t-1}\, e_{t-1}$	-1.03 (0.47)*		1.87 (0.53)**	
	$F_t\, e_t$	-0.66 (0.43)	0.38 (0.14)**	2.03 (0.48)**	0.44 (0.18)*
	f_{t-1}	-0.01 (0.24)			
	f_t	0.27 (0.28)	0.41 (0.11)**	0.44 (0.10)**	
	F_{t-1}				-0.55 (0.17)**
Adj-R^2		98.28%	98.02%	98.17%	98.21%
Log likelihood		-111.55	-117.88	-114.46	-113.02
Autocorrelation:	F-stat (prob.)	4.07 (0.02)	6.98 (0.00)	5.93 (0.00)	1.40 (0.25)
Q_t	Constant	0.65 (2.64)	1.11 (0.30)**	0.68 (0.37) †	-2.91 (2.12)
	$Q_{mt}e_t$	0.07 (0.05)	0.08 (0.04) †	0.09 (0.05) †	0.18 (0.08)*
	P_{t-1}	0.29 (0.11)*	0.19 (0.05)**		
	$F_{t-1}\, e_{t-1}$	0.76 (0.08)**	0.71 (0.06)**	0.76 (0.07)**	0.99 (0.16)**
	$F_t\, e_t$	0.58 (0.10)**	0.55 (0.09)**	0.56 (0.10)**	0.53 (0.13)**
	f_{t-1}	-0.04 (0.19)			
	f_t	0.08 (0.24)			0.18 (0.09)*
	Q_{t-1}	-0.13 (0.11)		0.13 (0.06)*	0.31 (0.09)**
	$Q_{mt-1}e_{t-1}$				-0.20 (0.09)*
	Q_{t-2}				-0.21 (0.06)**
Adj-R^2		99.02%	99.04%	98.95%	99.15%
Log likelihood		-95.97	-96.92	-100.19	-89.87
Autocorrelation:	F-stat (prob.)	4.50 (0.01)	4.66 (0.01)	11.12 (0.00)	3.04 (0.06)
Mis-specification:	LR-stat (prob.)	0.97 (0.32)	0.76 (0.38)	0.11 (0.74)	1.18 (0.28)

Note: **, *, † denote the significance of coefficients at 1%, 5%, 10% significance levels, respectively

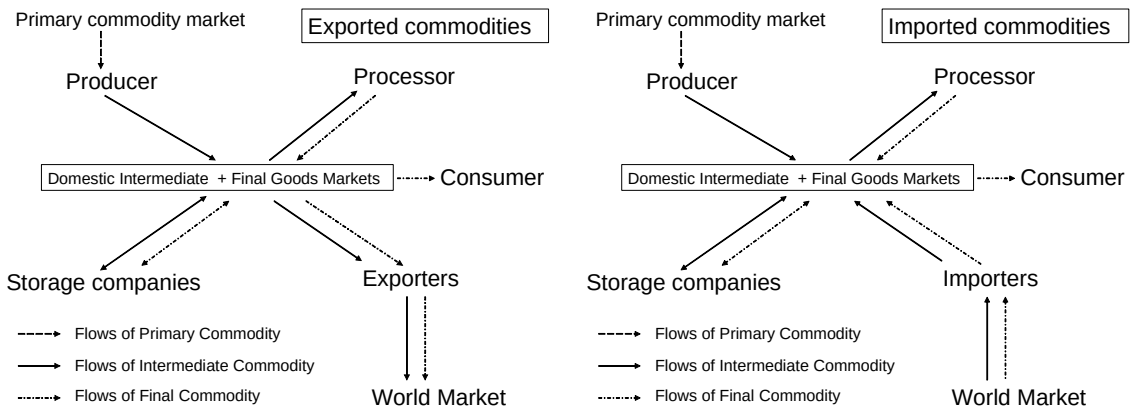
Table 5: Regression results of the Thai rice market

Equation	Variable	Model R1	Model R2	Model R3	Model R4
P_t	Constant	1084.03 (1027.87)	1084.16 (318.49)**	1102.59 (365.24)**	1140.78 (370.11)**
	Q_t	0.22 (0.07)**	0.27 (0.04)**	0.27 (0.03)**	0.28 (0.04)**
	P_{t-1}	0.42 (0.17)*	0.37 (0.11)**	0.36 (0.10)**	0.35 (0.10)**
	$F_{t-1}\, e_{t-1}$	0.05 (0.06)			
	$F_t\, e_t$	-0.02 (0.06)			
	f_{t-1}	-27.67 (17.36)			
	f_t	26.47 (26.71)			
Adj-R^2		84.79%	85.48%	85.49%	85.60%
Log likelihood		-292.62	-293.92	-293.92	-293.75
Autocorrelation: F-stat (prob.)		0.45 (0.64)	0.49 (0.61)	0.51 (0.60)	0.59 (0.56)
Q_t	Constant	-262.06 (974.63)	324.26 (785.98)	234.13 (369.61)	100.29 (241.04)
	$Q_{mt}e_t$	0.85 (0.06)**	0.89 (0.04)**	0.88 (0.04)**	0.84 (0.04)**
	P_{t-1}	-0.11 (0.12)		0.03 (0.08)	
	$F_{t-1}\, e_{t-1}$	0.02 (0.06)	0.11 (0.04)*	0.10 (0.06) †	
	$F_t\, e_t$	-0.06 (0.07)	-0.15 (0.06)*	-0.15 (0.06)*	-0.07 (0.04) †
	f_{t-1}	19.18 (19.73)			
	f_t	-4.38 (22.27)			
	Q_{t-1}	0.10 (0.08)			0.09 (0.03)**
Adj-R^2		97.43%	97.39%	97.33%	97.48%
Log likelihood		-290.22	-292.90	-292.84	-292.21
Autocorrelation: F-stat (prob.)		0.75 (0.48)	0.39 (0.68)	0.36 (0.70)	0.80 (0.46)
Mis-specification: LR- stat (prob.)		0.77 (0.38)	1.11 (0.29)	1.12 (0.29)	0.90 (0.34)

Note: **, *, † denote the significance of coefficients at 1%, 5%, 10% significance levels, respectively

Table 6: Descriptive statistics of estimated residuals

Statistics of Residuals	Rubber Equations		Rice Equations	
	P_t	Q_t	P_t	Q_t
Mean	2.6×10^{-15}	-5.92×10^{-15}	6.48×10^{-13}	6.11×10^{-13}
Standard Deviation	1.099	0.807	267.006	257.347
Skewness	-0.368	0.277	0.023	-0.439
Kurtosis	2.821	2.399	2.213	2.678
Jarque-Bera	1.793	2.085	1.088	1.530
Prob.	0.408	0.353	0.580	0.465
KPSS	0.175	0.112	0.084	0.061
H_0 : the series is stationary	I(0)	I(0)	I(0)	I(0)



(a) Exporting Country (b) Importing Country

Figure 1: Trade flows of intermediate and final commodities

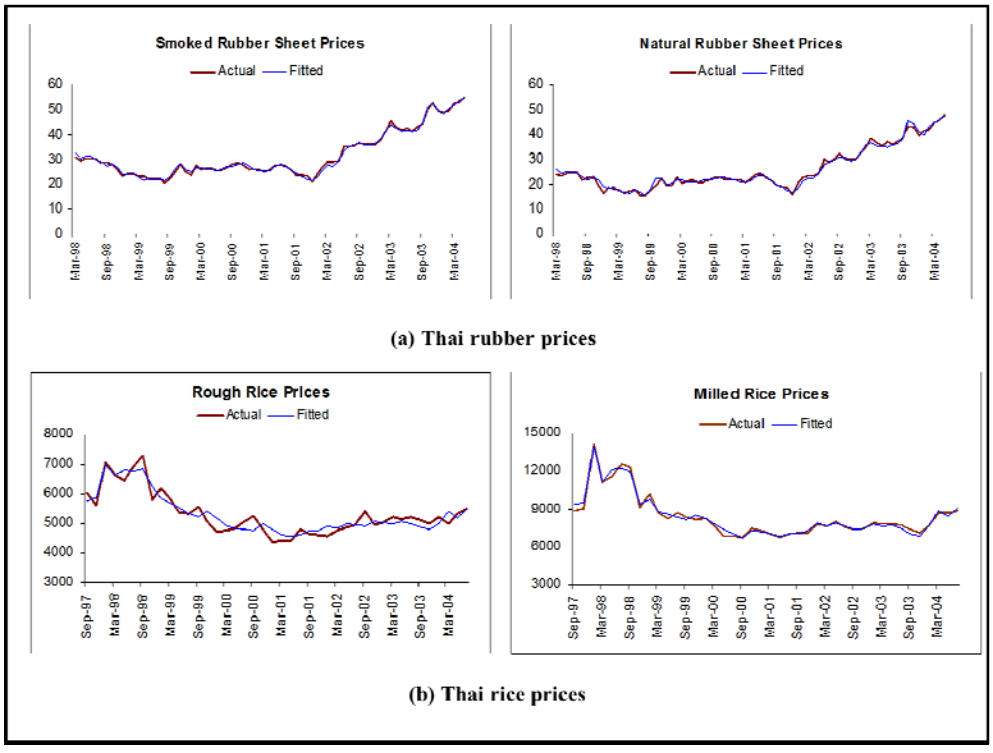


Figure 2: Fitted and actual values of domestic commodity prices