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Submitted Article

Exchange Rate Policy and Global Supply Chains: The Case of the Chinese Renminbi and Global Soybean and Soybean Product Markets

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Abstract *A policy debate on widespread currency manipulation has generated economic analyses to inform policymakers regarding both the extent and impact of the problem. Such analyses typically focus on commodity trade and price impacts while ignoring potentially important supply chain linkages. Using Chinese exchange rate policy and global soybean and soybean product markets as an example, this paper illustrates that substantial measurement errors are possible if supply chain linkages are ignored in exchange rate policy analyses. As a consequence, policy responses to foreign currency manipulation informed by such analyses may be misguided or imprecise at best.*

Key words: Supply chain, measurement error, renminbi, exchange rate, soybeans, China.

JEL codes: F14, Q14, Q17.

Using currency undervaluation to gain a trade advantage, stimulate economic growth, and create jobs has become so widespread across developed, developing, and newly-industrialized countries alike that the United States finds itself essentially engaged in a global "currency war" (Bergsten 2013). Although U.S. policymakers have raised concerns over the years about currency manipulation in general, related policy initiatives over the last decade have centered on Chinese exchange rate policy intended to facilitate China's rapid economic growth and its transformation into the "workshop of the world" through deliberately undervalued exports and overvalued imports (Morrison and Labonte 2013).

The U.S. policy response to this currency war has included a series of bills introduced in every session of Congress since 2003 aimed primarily at addressing the competitive advantage that a consistently undervalued

Renminbi (RMB) or Yuan, as the Chinese currency is known, has afforded Chinese producers and exporters in U.S. markets (Morrison and Labonte 2013).[1,2] Little policy concern has focused on the restrictive effects of an undervalued RMB on U.S. exports. Among other things, the Congressional legislation has sought authority to require countervailing duties on imports from currency undervaluing countries such as China. Frustrated by the ineffectiveness of legislation to bolster largely impotent U.S. currency law, bipartisan majorities of both houses of Congress, with support from private sector groups and labor unions, have insisted that the Trans-Pacific Partnership (TPP), a key international economic initiative of the current administration that must be approved by Congress, address the manipulation of exchange rates by member countries (Bergsten 2015). Although China has not participated in the TPP talks, including a currency chapter in the agreement would force negotiations on the exchange rate policies of other accused currency manipulating countries involved in the talks and thus set a precedent for future agreements in which China might participate.

The policy debate on currency manipulation has generated economic research to inform policymakers regarding both the extent and impact of the problem. For China, research largely agrees that the RMB was systematically undervalued over the years. The extent of the undervaluation, however, has been the subject of continuing debate (Morrison and Labonte 2013). Following the 1994 RMB devaluation, the currency was kept at a constant nominal level relative to the U.S. dollar despite numerous forces that normally would have led to an RMB appreciation, including China's rapid economic growth, rising productivity, strong and growing exports, and large foreign direct investment inflows (Funke and Rahn 2005). When China moved to a managed float of the RMB in 2005, the consensus among analysts (e.g., Funke and Rahn 2005; Goldstein and Lardy 2003a, b; Bergsten 2004) was that the RMB was undervalued against the U.S. dollar by between 15–25%. The RMB appreciated slowly under a new regime until 2008, when declining global demand for its products led China to peg the RMB to the dollar once again. Estimates of the RMB overvaluation during that period ranged from 12% (Reisen 2009) to 25% (Rodrick 2009), to 40% (Cline and Williamson 2009), and even to 50% (Ferguson and Schularick 2009). When the managed float regime was resumed in 2010, the RMB continued to appreciate slowly against the dollar, reaching approximate equilibrium by 2014 (Kessler and Subramanian 2014).

Research measuring the agricultural trade and price effects of the RMB undervaluation has taken primarily a single commodity or aggregate commodity group approach in which the expected effects of the undervaluation are straightforward—world trade and Chinese prices of a given commodity exported by China are expected to increase while prices in importing countries are expected to decrease (e.g., see Devadoss et al. 2014). The typical importing country policy recommendation based on such research would be

[1] *China's currency is officially known as the Renminbi (literally meaning "People's currency") and the Yuan is the basic currency unit. The equivalent for the United States would be "legal U.S. tender" with the "dollar" as the basic currency unit.*

[2] *For example, two bills designed to remedy the Chinese export subsidy effects of the RMB undervaluation on U.S. import-competing industries have been introduced in the 114th Congress (2015–2016) - the Currency Reform for Fair Trade Act (H.R. 820) and the Currency Undervaluation Investigation Act (S. 433). In April 2015, S. 433 was incorporated into the Trade Facilitation and Trade Enforcement Act of 2015 (S. 1015).*

an import restriction such as required in U.S. legislative proposals. For a commodity imported by China, the expected price effects of the RMB undervaluation in the single commodity or commodity group approach are in the same direction but world trade is expected to decline. Research findings consistent with expectations based on this approach would rationalize support in an exporting country for an export subsidy or other export incentive.

Most commodity markets, however, operate as components of vertical supply chains. As a result, the consequences of currency misalignments like the RMB undervaluation for a given commodity market and, therefore, the appropriate trade or domestic policy remedies are actually much less straightforward than a single commodity approach analyzing the market effects assumes. Changes in a country's exchange rate simultaneously affect markets of raw commodities and associated valued-added products all along their domestic and global supply chains. Exchange rate impacts at each market level transmit up and down the supply chain, confounding the effects at each level. As a result, estimating the trade and price consequences of currency manipulation in a given commodity market without considering supply chain interactions could lead to potentially important measurement errors.

Using Chinese exchange rate policy and global soybean and product markets as the example, this paper examines the consequences of ignoring supply chain interactions in analyses of the commodity market effects of exchange rate policy. Following a review of the exchange rate policy analysis literature and some theoretical issues, an econometric simulation model of world soybean and products markets is presented. The model is then used in a simulation analysis of the Chinese RMB undervaluation to illustrate the supply chain measurement error problem. The simulation results support a concluding discussion of the important implications for both domestic and trade policy.

Literature Review

Schuh (1974) is often credited with stimulating the large and growing body of literature on the relationship between exchange rates and agricultural markets, much of which focuses on U.S. markets and trade at an aggregate level. Anderson and Garcia (1989) and Mutuc et al. (2011) promote a single commodity approach to exchange rate analysis, suggesting that the effects of exchange rates are "more measurable" at lower levels of commodity aggregation. Shane et al. (2008) examine exchange rate impacts on U.S. agricultural exports across 12 commodity subcategories including soybeans. Numerous studies have examined the commodity-level trade effects of exchange rates, including Anderson and Garcia (1989) and Andino et al. (2005) for soybeans, Babula et al. (1995) for corn, Swift (2004) and Miljkovic and Zhuang (2007) for meat, Karemera et al. (2011) for vegetables, and Molina et al. (2013) for rice. Despite their contributions, none account for the supply chain effects of exchange rate changes or specifically consider the effects of the undervaluation of the Chinese RMB.

China's move to a managed float of the RMB in 2005 spawned a flurry of studies on the consequent aggregate trade effects. For example, Willem (2006), Whalley and Wang (2011), and Thorbecke and Smith (2012) used various methods to examine the impacts on the overall China-U.S. trade surplus. Chen (2011) and Zhang (2012) analyzed the response of aggregate bilateral trade flows to an RMB appreciation. A few studies have examined the commodity-level trade implications of RMB adjustments against foreign currencies, including Zhang et al. (2010) for soybeans, Izotov (2012) for 18 major commodities traded by China and Russia, Mutuc et al. (2011) for U.S.–China trade in corn, soybeans, and cotton, and Devadoss et al. (2014) for U.S.–China milk, soybean, bean, cotton, fruit, and fruit juice trade. Again, despite their contributions, none of these studies consider the effects of the observed level of RMB undervaluation over time, or account for interactions among markets along the respective commodity supply chains.

Theoretical Issues

Most agricultural commodity markets operate on the upstream segment of national and often global supply chains. Soybean markets, for example, are linked to soymeal and soyoil markets through the derived demand for soybean processing. Soymeal is commonly used as a protein supplement in livestock feeds, while soyoil is used in the manufacture of a variety of products like biodiesel fuel, cooking oil, and numerous food products. Capturing this derived demand behavior of a commodity market is key to accurately assessing the net changes that occur in that market from an exogenous shock like an exchange rate adjustment.

The importance of accounting for supply chain linkages in exchange rate analyses is illustrated in figures 1(a) and 1(b). In both figures, the first row of graphs represents world soybean markets while the second row represents downstream soybean product markets in which meal and oil are treated jointly only for expositional purposes. The right-hand column of graphs in each figure represents Chinese markets, while the left-hand column represents the "Rest of the World" (ROW). China is depicted in the top row of graphs in both figures as a soybean-importing country with an excess soybean demand (EDS_c). Despite the potential import-restricting effects of the RMB undervaluation, Chinese soybean imports experienced a meteoric rise when China opened its markets to trade in the mid-1990s: from 0.8 million metric tons (mmt) in 1993/94 to 69 mmt by 2012/13. China is now the world's largest soybean-importing country, accounting for 65% of world soybean imports.

In contrast, the ROW is depicted in both figures 1(a) and (b) as a net soybean-exporting region with an excess soybean supply (ESS_r) determined as the difference between the horizontal aggregations of the soybean supply and demand curves across all soybean producing and consuming countries other than China (ΣSS_i and ΣDS_i, respectively). The interaction of ESS_r and EDS_c determines the equilibrium world soybean quantity traded (Q^s_w) and the equilibrium price (P^s_w). World soybean product markets operate similarly in the bottom row of each figure.

Soybean and soybean product markets in each country are linked in the supply chain through the derived demand behavior of soybean markets. In soybean processing, soybeans are the input and soybean products the outputs. Thus, a Chinese soybean price (P^s_c) change, for example, negatively affects the Chinese soybean quantity demanded (DS_c), which shifts the vertical Chinese soybean product supply curve (SP_c) in the corresponding direction (bottom row of graphs in figures 1(a) and (b), given the technology-dependent soybean product extraction rate (Φ_c). A Chinese soybean product price (P^p_c) change, however, shifts China's soybean processing demand curve

Figure 1 Supply chain effects of RMB undervaluation: soybean to soybean product market

(a) Direct effects on soybean markets with indirect downstream effects on soybean product market

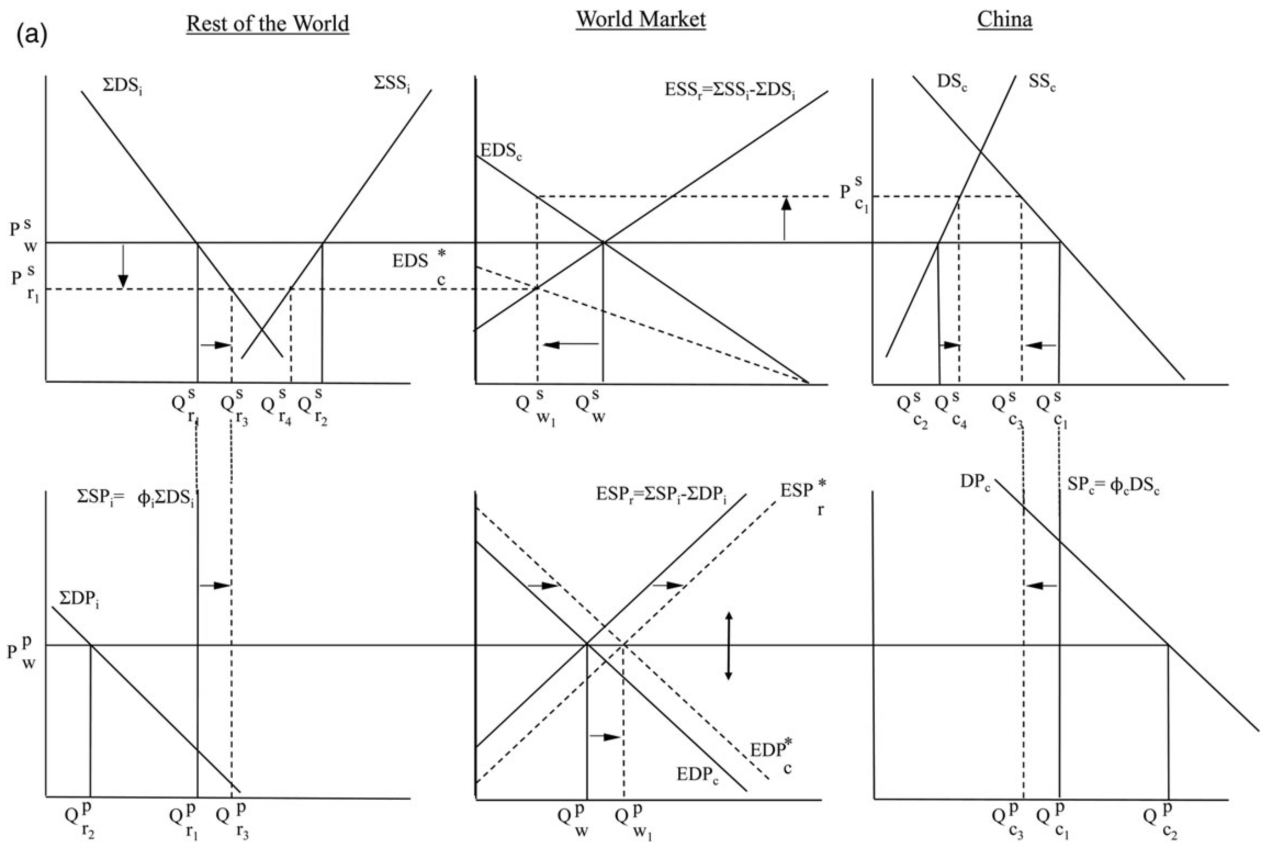
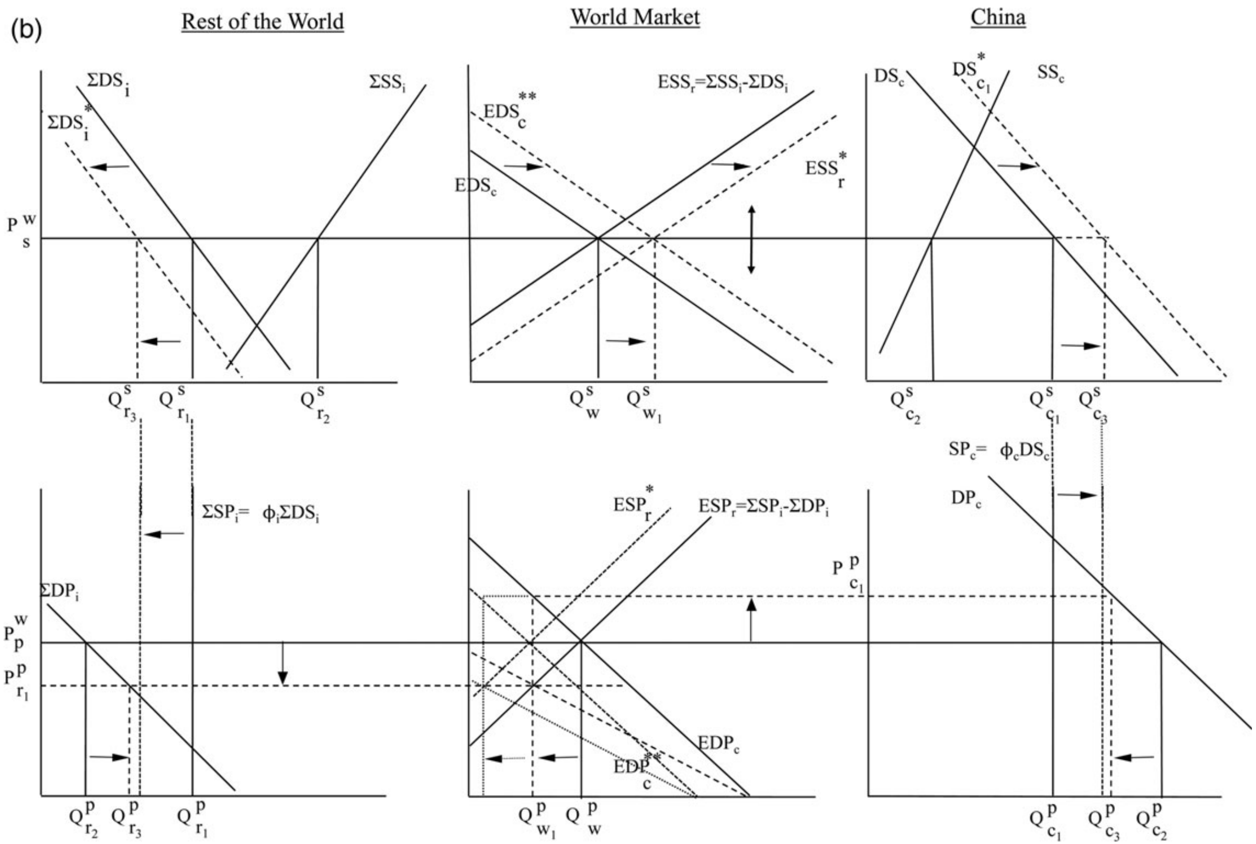


Figure 1 Continued.

(b) Direct effects on soybean product markets with indirect upstream effects on soybean markets



(DS_c), thus impacting soybean markets and prices. In turn, the shift in DS_c shifts SP_c in the same direction given Φ_c, which impacts product markets. Note that the vertical nature of the ROW and Chinese soybean product supply curves in each figure is a graphical device to depict the fact that soybean product supply can only change as its own price changes if soybean processors first respond to the price change by changing the volume of soybeans processed.

Now assume that China undervalues the RMB. Graphical analyses of exchange rate changes in a single commodity market often use a four-panel diagram to separate exporting and importing countries that operate in different currencies. To simplify the exposition of the supply chain effects of the RMB undervaluation in both figures 1(a) and (b), however, we use a three-panel diagram for each commodity (soybeans and soybean products) in which the right-hand column of graphs representing China are denominated in RMB while the left-hand column of graphs representing the ROW are denominated in a representative currency (U.S. dollars). In the middle column of graphs, the Chinese excess demand and supply curves (EDS_c and EDP_c) are denominated in Yuan, while the ROW excess supply curves (ESS_r and ESP_r) are denominated in U.S. dollars. The vertical axes in the world market graphs of both figures, therefore, represent prices in both RMB and in U.S. dollars at the equilibrium exchange rate such that $P_c = e_{\$}^{y} P_r$ for soybeans and for soybean products, where $e_{\$}^{y}$ is the equilibrium RMB/USD exchange rate.

The RMB undervaluation against the U.S. dollar (an increase in $e_{\$}^{y}$ to $e_{\$}^{y*}$) is illustrated in the traditional manner in the top row of figure 1(a) as a leftward rotation of the Chinese soybean excess demand curve to EDS_c^*. The undervaluation implies that each dollar price of soybeans is now associated with a higher RMB price along the vertical axis in the top middle panel, and that each RMB soybean price is now associated with a lower dollar price. In China, the higher RMB soybean price reduces the quantity of soybeans demanded for import. Also, the ROW receives a lower dollar price for each soybean bushel sold, which reduces the quantity of ROW soybeans available for export. The result is a reduction of world soybean trade from Q_w^s to $Q_{w_1}^s$, a lower dollar soybean price in the ROW ($P_{r_1}^s$), and a higher RMB soybean price in China ($P_{c_1}^s$).

The RMB undervaluation effects in the soybean market, however, transmit down the supply chain to soybean product markets. In the ROW, the lower soybean price increases the quantity of soybeans processed rather than exported ($Q_{r_1}^s$ to $Q_{r_3}^s$ in figure 1(a)), increasing the ROW soybean product supply ($Q_{r_1}^p$ to $Q_{r_3}^p$). The ROW excess soybean product supply then shifts out to ESP_r^*. The opposite process occurs in China, increasing the Chinese soybean product excess demand to EDP_c^*. Thus, the undervaluation in the soybean market indirectly increases ROW-China soybean product trade from Q_w^p to $Q_{w_1}^p$ (figure 1(a)). The effect on the soybean product price, however, is ambiguous and depends on whether the ESP_r shifts more or less to the right than EDP_c.

The foregoing assumes the undervaluation directly affects only soybean markets. The soybean product market effects are the indirect, supply chain consequences of the undervaluation in the soybean market. There are also direct effects of the undervaluation on soybean product markets that transmit indirect effects upstream to soybean markets as demonstrated in figure 1(b). A RMB undervaluation directly affecting only soybean product markets rotates the excess demand for soybean products to the left (EDP_c to EDP_c^{**}), resulting in a higher RMB-denominated soybean product price ($P_{c_1}^p$), a lower dollar-denominated soybean product price ($P_{r_1}^p$), and a decline in the China-ROW soybean product trade (Q_w^p to $Q_{w_1}^p$).

The soybean product price changes in figure 1(b) transmit upstream through the supply chain and shift the soybean processing demand because soybean product price changes affect the profitability of soybean processing. In the ROW, soybean processing demand shifts to the left (ΣDS_i to ΣDS_i^*) and the excess soybean supply to the right (ESS_i to ESS_r^*). In China, the opposite process occurs, resulting in a rightward shift of EDS_c to EDS_c^{**}. The result is an unambiguous increase in world soybean trade (Q_w^s to $Q_{w_1}^s$) as an indirect effect of the undervaluation in the soybean product market. The effect on the soybean price, however, is ambiguous and depends on whether ESS_r shifts more or less to the right than EDS_c.

Because the RMB undervaluation affects soybean and soybean product markets simultaneously, the net effects of the undervaluation on both soybean and soybean product trade and prices can be graphically illustrated by overlaying figures 1(a) and (b). The direct and indirect supply chain effects of the undervaluation on trade in both soybeans and soybean products tend to be offsetting so that the net effects are ambiguous. Compare, for example, the top middle panels of figures 1(a) and (b) in which the direct effects of the undervaluation on soybean trade (figure 1(a)) are the opposite of the indirect supply chain effects (figure 1(b)). The same is the case for soybean product trade (bottom middle panels of figures 1(a) and (b)). Also, the net effects on prices are analytically ambiguous. The final effects depend on the price elasticities of supply and demand in all countries and at all levels of the supply chain.

Methodology and Data

To analyze the supply chain consequences of the RMB undervaluation in soybean and product markets, this study utilizes a 186-equation econometric, price equilibrium simulation model of world soybean and product markets (see Williams 1985, 1999; Williams et al. 2002, 2014 for more details).[3] The model allows for the simultaneous determination of the supplies, demands, prices, and trade of soybeans, soymeal, and soyoil in seven major world trading regions (United States, China, Argentina, Brazil, the European Union (EU), Japan, and ROW).[4] Each region's domestic market is divided into four simultaneous blocks of equations (soybeans, soymeal, soyoil, and excess supplies and demands; figure 2).

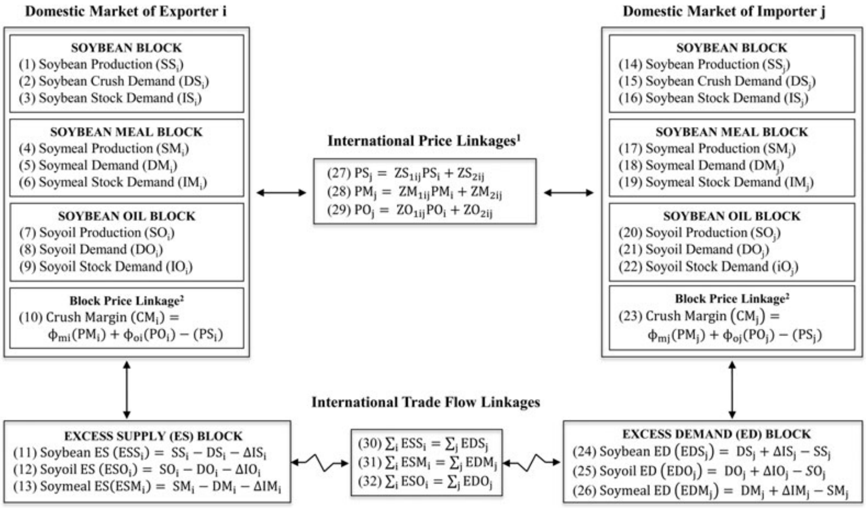
The soybean supply in each exporting and importing region (equations (1) and (14) in figure 2) is specified with acreage harvested and production equations:

$$SH_t = SH_t(PS_t^e, \alpha_t) \text{ and} \tag{1}$$

$$SS_t = SY_{kt} \cdot SH_{kt}, \tag{2}$$

[3]*Interested readers can also find details of this model in the Appendix of Supplementary Materials.*
[4]*Given the important simultaneous interaction between the U.S. soybean and corn markets, the model also includes the U.S. corn market, including acreage planted and harvested, production, demand, trade, and price equations.*

Figure 2 Structure of the global soybean and soybean product supply chain model



Note: Superscript i = any exporter i = 1,. . ., n; and j = any importer j = 1,. . .,k. Also, Δ should be read "change in." Superscript 1 indicates the Z_1 and Z_2 include all multiplicative (e.g., exchange rates and as valorem subsidies) and additive (transportation costs, specific tariffs, etc.) measures that come between prices of country i and j; Superscript 2 indicates that ϕm and ϕO are meal and oil extraction rates; PS, PO, and PM are soybean, soyoil, and soymeal prices, respectively.

where SH = soybean acreage harvested; SS = soybean production; SY = exogenous soybean yield; α = appropriate exogenous shift variables; t = time period; and PS^e = expected soybean farm prices for each region, which account for the relevant farm policies over time. Moreover,

$$PS^e = MAX(PS_{t-1}, LS_t) \cdot D5901 + MAX(PS_{t-1}, 0.85 \cdot TS_t + 0.15 \cdot MAX(PS_{t-1}, LS_t)) \cdot D0212, \quad (3)$$

where PS = the farm price of soybeans; LS = the soybean loan rate; TS = soybean target price; and D5901 and D0212 are policy regime indicator variables (1 in the indicated years of 1959/60 through 2001/02, and 2002/03 through 2012/13, respectively, and 0 otherwise). The U.S. soybean supply is disaggregated in the model into regional rather than national acreage planted, acreage harvested, and production equations to account for U.S. interregional competition.

The demands for soybeans, soymeal, and soyoil (D) in exporting and importing regions (equations (2), (5), and (8), and (15), (18), and (21), respectively, in figure 2) are specified as

$$D_{ist} = D_{ist}(P_{ist}, ß_{ist}), \quad (4)$$

where i = world region {1, . . ., 7}; s = commodity {soybeans, soymeal, and soyoil}; t = time period; P = domestic market price for meal and oil and crush margin for soybeans; and β represents appropriate shift variables.

The regional soymeal and soyoil supplies (equations (4) and (7) for meal and (7) and (20) for oil in figure 2) are specified as the value-added products of soybean crushing such that the supply of each product (S_p) is determined as the soybean volume processed (D_s) multiplied by the respective meal and oil extraction rates (φ) in each region:

$$S_{ipt} = \varphi_{ipt} D_{ist} \text{ where i } = \text{world region } \{1, \ldots, 7\} \text{ and } \\ p = \text{soybean product } \{\text{soymeal, soyoil}\}. \tag{5}$$

Simultaneous interaction of soybean and product markets along the supply chain in each region is ensured through the derived demand for soybeans as functions of the endogenous soybean crush margins (equations (10) and (23) in figure 2), which are the own price variables in the crush demand equations in each region (equations (2) and (15) in figure 2). The crush margin is the sum of the soymeal and soyoil prices (adjusted to soybean units), minus the soybean price.

The model is closed with net excess supply and excess demand relationships (equations (11)–(13) and (24)–(26) in figure 2) for exporting and importing regions, respectively, specified as the residual differences between their respective domestic soybean, soymeal, and soyoil supply and demand schedules.

The soybean and soybean product markets of the countries in the model are linked through international price and trade flow relationships. Price transmission equations following Bredahl et al. (1979) account for the effects of exchange rates as well as tariffs, export subsidies, border taxes, transportation costs, etc., and other factors that drive a wedge between soybean and product prices among world regions (equations (27)–(29) in figure 2). International market clearing conditions (equations (30)–(32) in figure 2) require equality of the world excess supply and demand for soybeans, soymeal, and soyoil in each time period.

A large amount of data is required to support the econometric parameter estimation and simulation of the model. For U.S. and foreign markets, much of the data was taken from USDA sources (e.g., USDA ERS 2014; USDA FAS 2014; USDA NASS 2014). Price data for other countries came primarily from various country-specific sources. Most international macroeconomic data (such as incomes, inflation rates, population, exchange rates, etc.) were taken from IMF (2014) and numerous country-specific sources.

For the simulation analysis, annual estimates of the equilibrium RMB/USD exchange rate over time were needed since the opening of Chinese soybean and products markets to trade in the mid-1990s. There are numerous methods of estimating an equilibrium exchange rate and the results can be vastly different for different methods (Cline and Williamson 2007; Morrison and Labonte 2013). In a series of semi-annual publications, however, Cline and Williamson (2008–2012) and Cline (2013 and 2014) provide a continuous, consistent set of fundamental equilibrium exchange rate estimates since 2008 for a number of countries, including China. Those estimates are used in the simulation analysis to represent the equilibrium RMB/USD exchange rate for the 2008–2013 period.

Given that no consistent estimate of the equilibrium RMB/USD exchange rate from a single source exists before 2008, the mean values of estimates in each year from various sources were taken to represent the equilibrium RMB/USD exchange rate over the 1994 to 2007 period. Table 1 provides the estimated equilibrium RMB/USD exchange rates used in the simulation analysis and the sources from which the estimates were taken or over which

Table 1 Actual and Estimated Equilibrium RMB/USD exchange rates, 1994–2013

Calendar Year	Actual RMB/USD[a]	Equilibrium RMB/USD	Percentage Undervaluation	Sources
1994	8.62	6.22	38.7	Chang and Shao (2004) Chang (2007) (1994–1999)
1995	8.35	6.64	25.8	
1996	8.31	6.92	20.2	
1997	8.29	6.99	18.6	
1998	8.28	6.82	21.5	
1999	8.28	6.48	27.7	
2000	8.28	5.85	41.6	Jeong and Mazier (2003), Frankel (2006), Chang and Shao (2004), Chang (2007)
2001	8.28	6.27	32.1	Chang and Shao (2004), Bénassy-Quéré et al. (2004)
2002	8.28	6.03	37.3	Chang and Shao (2004), Coudert and Couharde (2005)
2003	8.28	6.11	35.5	Chang and Shao (2004), Bénassy-Quéré et al. (2004), Coudert and Couharde (2005)
2004	8.28	6.34	30.5	Bénassy-Quéré et al. (2006)
2005	8.19	5.65	45.0	Cline (2005)
2006	7.97	6.56	21.5	Anderson (2006)
2007	7.61	5.57	36.5	Cline and Williamson (2008)
2008	6.95	5.28	31.5	Cline and Williamson (2008)
2009	6.83	4.87	40.2	Cline and Williamson (2009)
2010	6.77	5.55	22.0	Cline and Williamson (2010)
2011	6.46	5.13	26.0	Cline and Williamson (2011)
2012	6.31	5.91	6.8	Cline and Williamson (2012)
2013	6.20	5.85	6.0	Cline (2013)

Notes: Superscript [a] indicates IMF (2014). Period average.

an average was calculated. The data indicate that the RMB was substantially undervalued against the dollar by between 20% and 40% from 1994 through 2009, after which a substantial appreciation occurred.

To examine the effects of the RMB undervaluation on global soybean and product markets, a baseline simulation was first conducted in which the RMB/USD exchange rate was set at its actual historical value in the appropriate soybean, soymeal, and soyoil price transmission equations from 1993/94 through 2012/13. Two scenarios were then simulated with the model and the results were compared to those of the baseline simulation. In the first scenario ("with" supply chain interaction effects simulation), the historical values of the RMB/USD exchange rate were replaced by the estimated equilibrium rates in the soybean, soymeal, and soyoil price transmission equations and the model was simulated again for the 1993/94–2012/13 sample period. Differences in the simulated values for supplies, demands, prices, and other endogenous variables in the model across countries from those in the baseline simulation provide direct measures of the effects of the RMB undervaluation in global soybean and product markets when allowing for market interactions along the soybean-soybean product supply chain.

Typically, however, exchange rate analyses related to particular agricultural commodity markets ignore supply chain interactions as discussed earlier. Thus, in the second scenario ("without" supply chain effects simulation), the soybean and soybean product (soymeal and soyoil) markets first were separated in each country in the model by severing supply chain linkages to prevent interactions and feedback between the upstream (soybean) markets and downstream (soybean products) markets. Then, as in the first simulation, the historical values of the RMB/USD exchange rate were replaced in the modified model with the estimated equilibrium rates in the price transmission equations and the model was again simulated over the sample period.

Model Parameter Estimation and Model Validation

The parameters of the U.S. soybean and corn supply blocks of the model were estimated using the Nonlinear Iterative Seemingly Unrelated Regression (ITSUR) estimator with annual data ranging from 1960/61 through 2012/13. Normalization by an exogenous input price index maintained linear homogeneity in prices. The estimated parameters of the behavioral equations in all production regions in both blocks are unconstrained, consistent with a priori expectations in sign and magnitude, and statistically significant. The remaining parameters of the model were estimated by means of a truncated two-stage least squares (2SLS) procedure based on principal components using data from 1960/61 through 2012/13 for some equations, but shorter time periods for other equations across countries in cases of limited data availability.[5] The model regression statistics indicate an excellent fit for the data and no evidence of autocorrelation. Also, the signs and sizes of all estimated parameters in each model equation are consistent with a priori expectations. The estimated own-price price elasticities of soybean supply and of soybean, soymeal, and soyoil demand across countries in the model are also provided in table 2.

[5]The 2SLS, principal components estimator used here, and first proposed by Kloek and Mennes (1960), is consistent since it may be reduced to an instrumental variables estimator (Brundy and Jorgenson 1971).

Table 2 Global Soybean and Soybean Product Model Estimated Price Elasticities[a]

	Acreage Planted		Domestic Demand		
	Short Run	**Long Run**	**Soybeans**[b]	**Soymeal**	**Soyoil**
United States			0.03***	−0.24***	−0.10***
Atlantic	0.60***	2.21***			
Corn Belt	0.16***	0.67***			
Delta	0.37***	1.79***			
Lakes	0.25***	0.71***			
Other	0.57***	2.44***			
Plains	0.28***	2.02***			
South	0.96***	4.14***			
	Acreage Harvested				
Brazil	0.37***	1.13***	0.11**	−0.19***	−0.10***
Argentina	0.18***	0.79***	0.14***	−0.19**	−0.15***
China	0.22***	0.76***	0.05**	−0.05*	−0.03***
European Union			0.04***	−0.09***	−0.15***
Japan			0.01	−0.54***	−0.25***
ROW[c]			−1.00[c]	−1.00[c]	−1.00[c]

*Notes: Asterisks indicate *ρ < 0.10, **ρ < 0.05, and ***ρ < 0.01; blank space implies irrelevance. Superscript [a]indicates that elasticities are evaluated at the means of the data based on the coefficients used in the simulation model; [b]indicates elasticities of domestic demand with respect to the gross soybean crushing margin for all countries except ROW, which is the elasticity of import demand with respect to soybean price; [c]constrained coefficient.*

Validation of the structural model included both a check of the dynamic, within-sample (*ex post*) simulation statistics for the fully simultaneous structural model and a sensitivity analysis to check the stability of the model. The dynamic simulation statistics indicated a highly satisfactory fit of the historical, dynamic simulation solution values to observed data. All Theil U coefficients were small, with most being less than 0.2. The Theil bias error proportions indicated no systematic deviation of simulated from actual data values for any of the endogenous variables. Also, a sensitivity test indicated that the model is stable to changes in the RMB/USD exchange rate with all endogenous variables returning to equilibrium within a reasonable time period (most within 5 years) following a 50% one-period shock in the RMB/USD exchange rate.

Effects of the RMB Undervaluation on U.S. Soybean and Product Trade and Prices

The "without" supply chain effects simulation represents the typical approach to measuring exchange rate effects on agricultural trade in an upstream commodity market like soybeans or a downstream commodity market such as soybean products in which supply chain linkages and feedback between upstream and downstream markets are ignored. The "with" supply chain simulation provides a more precise measure of those effects for soybeans and products and offers insight on the potential measurement error from ignoring supply chain linkages. The measurement error is calculated as the percentage over- or under-estimation of price or quantity effects from assuming away supply chain linkages.

Upstream (Soybean) Market Effects of the RMB Undervaluation

In the "without" simulation, the RMB undervaluation reduces world soybean trade by about 6%, on average, over the 1993/94–2012/13 simulation period (table 3). The estimated average annual decline in Chinese soybean imports (4.2 million mt) in this simulation scenario is greater than the estimated decline in total world soybean trade (3.5 million mt). The lower estimated world soybean prices (outside of China) of about 3–4% increased soybean demand by other importing countries (EU, Japan, and ROW) by up to 3%, resulting in a shift in destination of some soybeans away from China. The U.S. soybean exports decline by 4% over the simulation period compared to the 8.6% and 8.2% soybean export reductions by Argentina and Brazil, respectively. The U.S. farm price and income support policies over the years have worked to moderate the negative price impact on U.S. production induced by the undervaluation, limiting the reduction in the availability of U.S. soybean supplies for export.

As expected, soybean prices in the "without" scenario are estimated to have been lower in soybean exporting countries (3–4%) and higher in China (21–23%), on average, over the simulation period as a result of the RMB undervaluation. The relatively larger percentage change in Chinese soybean prices than in those of other countries is not surprising. Challenged by the need to expand foodgrain production to feed a rapidly-growing population while facing growing demand for land for feedgrain and oilseed production to support a rapid expansion of its livestock industry, the Chinese government opted to implement price support and subsidy policies to enhance the relative profitability of foodgrain over feedgrain production (Lohmar et al. 2009). Heavy government investment in soybean crushing facilities in port cities, relatively low soybean yields, and a growing shift in domestic production to food-grade soybeans provided additional stimuli to Chinese soybean imports for processing to meet the rapidly-growing demands for soymeal as a livestock feed protein supplement and for soyoil for cooking (Donley 2011). These Chinese soybean policies have necessarily reduced the price responsiveness of Chinese soybean import demand relative to that of world soybean excess supplies. The results imply that China bore much of the burden of its own exchange rate policy over the years in terms of impacts on both its imports and prices of soybeans.

In the "with" supply chain simulation, allowing supply chain interactions among upstream (soybean) and downstream (product) markets impacts the measurement of the global soybean market effects of the RMB undervaluation. Although China continues to bear the burden of the undervaluation in this simulation, the estimated absolute effects on both world soybean trade and prices are smaller (table 3). Undervaluation raises both soybean and soybean product prices in China so that the soybean crush margin and, therefore, the Chinese soybean crush volume and imports decline by less than in the "without" scenario. The result is a smaller reduction in the global soybean trade (5.2% compared to 6.0%), implying a 17% overestimation of the soybean trade effect of the undervaluation when supply chain interactions are assumed away (table 3).

Because Chinese soybean import demand and world trade declined by less in the "with" than in the "without" scenario, the estimated soybean price decline in exporting countries was also less (e.g., 3.0% compared to 3.7% for the U.S. soybean farm price). Also, the estimated increase in the

Table 3 Average Change in Global Upstream (soybean) and Downstream (soymeal) Markets from Undervaluation of the Chinese Renminbi, with and without Accounting for Supply Chain Effects, 1993/94–2012/13

Average Change in:	**With Supply Chain Effects**		**Without Supply Chain Effects**		**Measurement Error**
	Change	**% Change**	**Change**	**% Change**	**%**
Soybeans (Upstream Market)					
Exports (1,000 mt)					
U.S.	−1,030.6	−3.5	−1,187.3	−4.0	15.2
Argentina	−529.9	−7.5	−618.4	−8.6	16.7
Brazil	−1,398.3	−7.0	−1,653.4	−8.2	18.2
Total	−2,958.8	−5.2	−3,459.2	−6.0	16.9
Imports (1,000 mt)					
European Union	424.5	3.0	291.3	2.0	−31.6
Japan	9.0	0.3	6.6	0.2	−26.7
China	−3,714.6	−13.9	−4,159.5	−15.3	12.0
Rest of the World	322.4	2.7	402.5	3.4	24.8
Total	−2,958.8	−5.2	−3,459.2	−6.0	17.0
Prices					
U.S. Farm Price (USD/mt)	−8.43	−3.0	−10.53	−3.7	24.9
U.S. Wholesale Price (USD/mt)	−8.74	−2.9	−10.91	−3.6	24.8
China Farm Price (Yuan/mt)	468.92	23.7	452.71	22.7	−3.5
China Import Price (Yuan/mt)	549.32	22.2	530.30	21.3	−3.5
Argentina Export Price (Pesos/mt)	−21.30	−2.3	−27.48	−3.0	29.0
Brazil Export Price (Reales/mt)	−17.54	−3.0	−22.42	−3.8	27.8

Continued

Table 3 *Continued*

Average Change in:	With Supply Chain Effects		Without Supply Chain Effects		Measurement Error
	Change	% Change	Change	% Change	%
Soymeal (Downstream Market)					
Exports (1,000 mt)					
United States	−95.7	−1.3	−63.2	−0.9	−34.0
Argentina	−198.8	−1.1	−28.5	−0.2	−85.7
Brazil	−330.5	−2.6	−67.4	−0.5	−79.6
China	−710.8	[a]	–	–	–
Total	−1,335.7	−3.4	−159.1	−0.4	−88.1
Imports (1,000 mt)					
European Union	−363.2	−1.9	143.3	0.8	[a]
Japan	−41.4	−3.0	16.4	1.2	[a]
China	–	–	−602.7	[b]	–
ROW	−931.1	−4.9	283.9	1.6	[a]
Total	−1,335.7	−3.4	−159.1	−0.4	−88.1
Prices					
U.S. Wholesale Price (USD/mt)	−8.79	−3.4	−3.44	−1.3	−60.9
China Import Price (Yuan/mt)	521.16	21.6	440.43	17.7	−15.5
Argentina Export Price (Pesos/mt)	−5.97	−2.6	−2.33	−1.0	−61.0
Brazil Export Price (Reales/mt)	−7.91	−3.2	−3.09	−1.2	−60.9

Notes: Superscript [a]indicates undefined percentage change between negative and positive numbers; [b]large calculated percentage change due to a denominator near zero; − = not applicable.

Chinese soybean farm price was higher (23.7% compared to 22.7%). The consequent measurement error for soybean prices is higher than for soybean trade (25% for the U.S. soybean farm price and 27.8% and 29% for Brazilian and Argentine soybean export prices, respectively).

Downstream (Soymeal) Market Effects of the RMB Undervaluation

In downstream markets, the RMB undervaluation also leads to the standard results of lower world trade with higher prices in China and lower prices in other countries in the "without supply chain effects" scenario. For example, global soymeal trade is lower by 0.4% with a 17.7% higher soymeal price in China, and about 1% lower soymeal prices in other countries (table 3). Also, the estimated average decline in Chinese soymeal imports in the "without" scenario (602,700 mt) is greater than the estimated decline in total world soymeal trade (159,100 mt). The lower estimated world soymeal prices (outside of China) somewhat increased soymeal demand by other importing countries (EU, Japan, and ROW), resulting in a shift in destination of some soymeal away from China.

Given that, on average, China has historically been a marginal net importer of soymeal, the analytical conclusion under this scenario is that the RMB undervaluation stimulated Chinese soymeal production and reduced Chinese meal consumption sufficiently to keep China from importing a substantial quantity of soybean meal (602,700 mt on average over the sample period). The "with" simulation scenario, however, leads to quite different analytical conclusions. In this scenario, the RMB undervaluation actually prevents China from exporting a substantial quantity of soymeal (710,800 mt), rather than importing a substantial quantity as occurs when ignoring supply chain linkages (table 3). The undervaluation-induced increase in the Chinese soybean price and the correspondingly lower level of Chinese soybean processing and imports in the "with" scenario resulted in sufficiently lower soymeal production given the level of demand that China was a marginal net soymeal importer over the sample period rather than a net exporter. Thus, allowing for supply chain linkages with no RMB undervaluation over the sample period, China would have imported more soybeans (see table 3) and produced sufficiently more soymeal to allow a switch from marginal net soymeal imports (18,700 mt) to substantial net soymeal exports (692,100 mt) for an export increase of 710,800 mt (table 3).

As a result, the "with" simulation concludes that the RMB undervaluation reduced world soymeal trade by substantially more than in the "without" simulation (1,335,700 mt compared to 159,100 mt) because the undervaluation prevented soymeal exports from China and further reduced soymeal exports from all exporting countries (table 3). The consequence is also lower soymeal imports by non-China importing countries and higher world soymeal prices in the "with" simulation.

The downstream soymeal market measurement error from ignoring supply chain linkages in the RMB undervaluation analysis is substantial and generally negative compared to the generally positive measurement error in the soybean market (table 3). Assuming away supply chain linkages results in an 88% underestimate of the negative effect of the RMB undervaluation on world soymeal trade. The soymeal price decline in exporting countries from the undervaluation is underestimated by about 60% when supply chain linkages are ignored. Likewise, the Chinese soymeal price increase is underestimated by 15%. The analysis concludes that the RMB undervaluation prevented China from becoming a substantial soymeal importer when supply chain linkages are ignored, rather than a substantial soymeal exporter when accounting for those linkages. Also, soymeal imports by non-China importing countries are incorrectly estimated to increase rather than decrease.

Conclusions and Policy Implications

Exchange rate analyses typically focus on commodity trade and price impacts while ignoring potentially important supply chain linkages. Because exchange rate adjustments impact all market segments along a supply chain simultaneously, however, the effects on any one segment can be confounded by the transmission of the effects on other segments up and down the supply chain. In this article we have demonstrated that the consequence of ignoring supply chain interactions in exchange rate analyses can lead to substantial measurement error.

In our example of Chinese exchange rate policy and world soybean and product markets between 1993/94 and 2012/13, a simulation analysis of the Chinese RMB undervaluation concludes that ignoring supply chain linkages results in a 17% overestimate of the negative impacts of the undervaluation on world soybean trade, a 25–30% overestimate of the negative effect on world soybean prices, and a 3.5% underestimate of the positive effect on Chinese soybean prices. In soybean product markets (using soymeal as the example), ignoring supply chain linkages underestimates the negative trade effect of the undervaluation by 88%, underestimates the positive Chinese price effects by just over 15%, underestimates the negative price effects in exporting countries by 60%, and incorrectly estimates a positive rather than a negative effect on world imports. In addition, if supply chain linkages are ignored, the analysis concludes that the undervaluation has prevented substantial Chinese soymeal imports rather than preventing substantial Chinese soymeal exports when supply chain linkages are allowed.

Admittedly, the use of different RMB undervaluation estimates as well as different price and exchange rate transmission parameters in the model could produce different results. However, the RMB undervaluation estimates are taken from well-regarded studies of Chinese exchange rate policy and, thus, appropriately represent the generally-accepted pattern of RMB undervaluation over time. Also, the price parameters used in the model are not assumed but rather generated econometrically using a systems estimator providing some confidence in the internal consistency and accuracy of the parameter estimates.

Nevertheless, however accurate the results presented in this study for world soybean and soybean product markets may be, there is no reason to believe that either the magnitude or direction of effects of the RMB undervaluation on those markets would hold for any other commodity supply chain. The expected effects of the undervaluation for any commodity supply chain are largely ambiguous and dependent on the structure of the market being analyzed and the elasticities of supply and demand across markets. At a minimum, the results of this study are strongly suggestive of the measurement error inherent in any exchange rate analysis when supply chain linkages are ignored.

The supply chain bias problem has potentially important implications for policymakers. Strategies unilaterally implemented through some regional or multilateral trading agreement (such as the Trans-Pacific Partnership) to counter the market effects of foreign currency manipulation that are informed by analyses which ignore supply chain interactions may be misguided or at least imprecise. In the case of the undervalued Chinese RMB over the years, recommendations for a U.S. trade policy response to its restrictive effects on U.S. soybean exports based on such analyses would have tended to overestimate the amount of the trade incentive needed. On the other hand, recommended U.S. trade policy countermeasures in downstream soymeal markets would have tended to underestimate the amount of trade incentive required in those markets. Chinese policymakers faced the same problem in designing policies to offset the restrictive effects of the undervaluation on their own imports of soybeans and soybean products if the supporting analyses ignored supply chain interactions.

Along with China, several other countries have been accused in recent years of artificially holding down their currencies to boost their exports and limit their imports, including Denmark, Hong Kong, South Korea, Malaysia, Singapore, Switzerland, Taiwan, and Japan, most of which carry trade surpluses with the United States (Morrison and Labonte 2013). Consequently, U.S. policy interest in designing appropriate strategies to deal with currency manipulation will likely continue along with the need for accurate estimates of the trade and price effects of exchange rate manipulation. Models that explicitly account for supply chain interactions will be particularly useful in that effort.

There are domestic policy implications as well. Schuh (1974) argued that exchange rate policy can induce U.S. farm policy; he contended that during the 1970s an overvalued dollar contributed to low prices in the U.S. agricultural sector, which in turn induced farm bill legislation to support farm prices and incomes. A critical policy question during that period was how high to support prices and incomes. Recommendations for the level of price support needed to offset the effects of the overvalued dollar during that period might have been imprecise, unnecessary, or even in the wrong direction if they were based on typical exchange rate analyses that ignored supply chain interactions. In the case of soybeans and the undervalued Chinese RMB, recommendations to support the farm price based on such analyses would have overestimated the amount of price support required. Likewise, if informed by typical exchange rate analyses, measures to counter the negative price effects of the undervaluation on downstream market prices would have overestimated the price support needed in those markets. As with trade policy, understanding the consequences of foreign exchange rate manipulation for farm prices and the appropriate farm policy response will benefit from using models that account for supply chain interactions.

Supplementary Material

Supplementary material is available at *Applied Economic Perspectives and Policy online* (http://aepp.oxfordjournals.org/).

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