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Exchange Rates, Foreign Income, and U.S. Agricultural Exports

Mathew Shane, Terry Roe, and Agapi Somwaru

While it is generally accepted that change in the real value of the dollar is an important determinant of exports, it has not been rigorously demonstrated that this relationship, derivable from theory, holds empirically for agricultural exports and the components of agricultural exports. Starting with a dynamic maximizing framework, this paper estimates the real trade-weighted exchange rate and trade partner income effects on U.S. agricultural exports. For the period 1970–2006, a one percent annual increase in trade partners' income is found to increase total agricultural exports by about 0.75 percent, while a one percent appreciation of the dollar relative to trade partner trade-weighted currencies decreases total agricultural exports by about 0.5 percent. While these effects carry over to 12 commodity subcategories, they are conditioned by differences between bulk and high value commodities, and differences in the export demand from high compared to low income countries. We use a directed acyclic graphs (DAG) technique to identify the inverted fork causal relationships from vector autoregression (VAR) models. We also find that there is an asymmetric exchange rate effect so that the negative effect of exchange rate appreciation on exports sometimes dominates the positive effect of foreign income growth.

Key Words: exchange rates, U.S. agricultural trade, U.S. agricultural commodity exports, U.S. agricultural export prices, foreign income

The exchange rate and foreign income growth are commonly assumed to be important macroeconomic variables affecting U.S. agricultural exports. Ample evidence suggests that the growth in demand for U.S. agricultural exports is caused by growth in trade partner real income, but strong empirical evidence is lacking on the effect of changes in the value of the dollar on U.S. agricultural exports. We utilize the ERS Exchange Rate Data Set, which defines commodity-specific real effective exchange rates based on commodity trade-partner export weights. The export-weighted exchange rates and trade-partner real gross domestic product are found to strongly affect the demand for aggregate U.S. agricultural exports. A similar relationship appears to hold for many subcategories of agricultural exports, although differences in magnitude between bulk and high value exports are evident. Some of these differences appear to be linked to the tendency for bulk commodities to be exported to lower income countries, while the high value commodities tend to be exported to higher income countries. We also find that growth in trade partner real GDP has positively influenced growth in U.S. exports over the period 1970–2006, while changes in the real trade-weighted exchange rate have tended to constrain exports.

Knowing the effects of exchange rate and foreign income on U.S. agricultural exports is important for understanding the impact of policies directed toward economic growth and development, compared with those designed to address major macroeconomic imbalances. How these effects are likely to vary by commodity group is also important. For example, the higher the in-

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The authors dedicate this paper to the memory of G. Edward Schuh, who died on May 4, 2008. He was a pioneer in broadening the scope of agricultural economics. His proposition that what happens outside of agriculture can be more important than factors affecting agriculture directly has become only more insightful with time. We also express our appreciation to David Orden and Carlos Arnade for their helpful insights on an earlier draft of this paper. An anonymous reviewer and David Bessler also assisted us in understanding the causal links underlying the empirical aspects of the paper. We appreciate the suggestions of the reviewers and acknowledge that the paper is better because of them.

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come elasticity of export demand, the larger the impact of trade partner income growth on increasing the demand for U.S. agricultural exports. This also suggests the evolution of a policy to target exports to high potential demand countries. The higher the price elasticity of a commodity real trade-weighted exchange rate, the more competitive is the international market for exports of a particular country, and the more sensitive are U.S. exports of this commodity to policy-induced distortions in trade partner currencies.

It has been difficult to find empirical evidence linking the relative value of the U.S. currency to exports in spite of the tendency for conceptual models to predict such a relationship. In his award-winning article, G. Edward Schuh (1974) argued that a major part of the farm problem of the 1950s could be attributed to an overvalued dollar, which depressed agricultural prices and exports. He attributed the post Breton Woods agricultural export boom of the 1970s to the depreciation of the dollar, a depreciation that was in turn linked to monetary expansion as the United States attempted to monetize the effects of the first energy shock.

Conceptual contributions following this earlier work are based on static general equilibrium concepts such as that used by Dornbusch and Fischer (1980). They extended the static model of Salter (1959) to show how household expenditures that exceed total factor earnings can cause an increase in the relative price of home goods. The rise in price pulls resources from the production of traded goods while at the same time increases the consumption of both home and traded goods. The country experiences an appreciation of its real exchange rate, a trade imbalance, and a corresponding capital inflow. However, if a market for a country's currency is incorporated into this static model, then equilibration causes the nominal exchange rate to depreciate. This, in turn, leads to a rise in the domestic price of traded goods, and depreciation of the real exchange rate, which, in a frictionless full information environment, returns the economy to the initial equilibrium. A monetary shock causing expenditures to exceed factor income has no effect in real terms. Real effects result only when a country-specific structural change occurs, such as a shock to factor productivity.

The more recent conceptual and empirical analyses have embodied the Salter type of reasoning but in a dynamic context where markets exhibit sticky price adjustments, or countries differ in their rate of time preference and rates of factor productivity growth. Chari, Kehoe, and McGrattan (2004) calibrate a general equilibrium intertemporal model to data on eleven OECD countries. Price adjustments are sticky in adjusting to shocks that cause expenditures to depart from factor income.[1] They find that if prices are held fixed for at least one year, and risk aversion is relatively high, then the volatility of real exchange rates generated by their structural model is consistent with some features of the data. In a partial equilibrium context, Hughes and Penson (1985) and Rausser et al. (1986) also focused on the stickiness of prices to explain how monetary shocks that cause real exchange rate appreciation can cause agricultural prices to overshoot their longer-run equilibrium.

Empirical work (e.g., Bessler 1984, Orden 1986a and 1986b, and Orden and Fackler 1989) has drawn upon modern time-series methods. Even here, however, it has been fairly difficult to show that monetary shocks have measurable effects on agricultural prices and trade. Shocks to U.S. financial market variables are found to explain about 20 percent of forecast error variance for exports, and about 10 percent for real agricultural prices one year ahead, and about 50 and 20 percent respectively for a three-year forecast horizon. Rose (1990, 1991) and Ostry and Rose (1992) also found that a real devaluation has generally no significant impact on trade. Another line of query has focused on exchange rate volatility and agricultural exports (see Asseery and Peel 1991, Awokuse and Yuan 2006, Cho, Sheldon, and McCorriston 2002, Langley et al. 2002, Pick 1990, and others). In general, while the results of these studies are somewhat ambiguous, the overall conclusion is that exchange rate volatility tends to negatively affect country exports, particularly for developing countries.

Our approach follows that of Senhadji and Montenegro (1998). They construct an intertemporal model from which they derive a reduced form "total" export-demand function with real

[1] Obstfeld (2002) studies exchange rate adjustments from the perspective of the New Open Economy Macroeconomics. He argues that some approaches have led to an unwarranted "elasticity pessimism" of adjustment to shocks. His findings for the case of trade between the United States and Canada suggest that "exchange rate changes alter relative international prices in conventional ways" (p. 16).

weighted GDP per capita and the real trade-weighted exchange rate as activity variables. They fit this model to panel data of 60 countries, and find long-run income elasticities averaging about 1.5, while exchange rate elasticities tend toward unity. We adapted their model to U.S. commodity exports. Our point estimates over twelve commodity categories tend to bracket their results, and suggest that for the period 1970–2006, the growth in demand for U.S. agricultural exports has been strongly enhanced by growth in trade partner traded-weighted real GDP, and negatively affected by the appreciation of the U.S. traded-weighted exchange rate. We find that these effects are conditioned by differences between bulk and high value commodities. These differences are, in turn, closely associated with export demand from high compared to low income countries, with U.S. exports to low income countries being more exchange-rate sensitive than exports to high income countries. We further examine the contemporary relationships among exports, the trade-weighted real exchange rate, and the weighted sum of a country's real GDP by applying the directed acyclic graphs (DAG) technique. We find that GDP and exchange rate depict an inverted fork causal relationship with exports.

In the next section, the structural model is presented. This is followed by a review of the data used in the analysis. We then discuss the results and implications from fitting the model to data.

The Model

We use a Ramsey-style general equilibrium framework similar to that used by Senhadji and Montenegro (1998) to derive the specification of the empirical model.[2] Strong assumptions are necessary to derive this equation so that it can be estimated with available data.

Consider a three-country world: the United States, a foreign country, and the rest of the world (ROW). Further assume that the United States trades only with the foreign country. Let j indicate the source of the foreign country's imports, with $j = 1, 2$ denoting imports from the United States and the rest of the world, respectively. At each instant in time, infinitely-lived households in the foreign country consume d^* of their domestically produced good, denoted by e^*, and expend m^* on imported goods.[3] The prices of the goods imported from the United States and the rest of the world are denoted by (p_{m1}, p_{m2}), and expressed relative to the numeraire price of the domestically produced good e^*. The quantities imported are denoted by (m_1^*, m_2^*). The difference between domestic supply and consumption $(e^* - d^*)$ equals the country's exports, denoted x^*. Household earnings accrue from the stock of bonds b^* at the world interest rate r and the flow of factor payments. Factor payments, in turn, equal the value of the domestically produced goods, e^*. The stock of bonds b^* evolve according to $\dot{b}^*$, which can be positive or negative.

The decision problem of the representative household in the foreign country is to maximize the discounted present value of utility[4]

$$\underset{\{d^*,\, m_1^*,\, m_2^*\}_{t=0}^{t=\infty}}{Max} : \int_{t=0}^{t=\infty} u(d^*, m_1^*, m_2^*) Exp(-\delta t) dt ,$$

subject to the flow budget constraint

$$\dot{b}^* = b^* r + (e^* - d^*) - p_{m1} m_1^* - p_{m2} m_2^* ,$$

where $u(d^*, m_1^*, m_2^*)$ is the period utility function and δ is the rate of time preference. A transversality condition is also imposed to rule out a Ponzi scheme.

To economize on the number of explanatory variables given our rather short time series of data, and to permit the estimating equations to be linear, we presume that the period utility function is addilog:

[2] Strong separability and functional form assumptions are necessary to derive an aggregate export demand equation that can be used with existing data. In spite of this limitation, the estimation results are consistent with the theory.

[3] We use "*" to denote the foreign country.

[4] This structure presumes finite-lived agents with perfect foresight that are connected through a pattern of intergenerational transfers based on altruism (see Barro and Sala-i-Martin 2003, p. 86). It can be shown that this problem yields the familiar Euler equation of optimal expenditure, E, over time, which is given by $r - \delta = \dot{E} / E$.

$$u(d^*, m_1^*, m_2^*) = B_o d^{*(1-\beta_o)}(1-\beta_o)^{-1} + B_1 m_1^{*(1-\beta_1)}(1-\beta_1)^{-1} + B_2 m_2^{*(1-\beta_2)}(1-\beta_2)^{-1},$$

which imposes strong separability.

From the present value Hamiltonian,

$$J = u(d^*, m_1^*, m_2^*) \quad Exp(-\delta t) + \nu[b^*(r-n) + (e^* - d^*) - p_{m1}m_1^* - p_{m2}m_2^*],$$

where ν is the co-state variable, we obtain the first-order conditions:

(1) $$\frac{\partial J}{\partial d^*} = B_o d^{*-\beta_o} Exp(-\delta t) = \nu$$

(2) $$\frac{\partial J}{\partial m_1^*} = B_1 m_1^{*-\beta_1} Exp(-\delta t) = \nu p_{m1}$$

(3) $$\frac{\partial J}{\partial m_2^*} = B_2 m_2^{*-\beta_2} Exp(-\delta t) = \nu p_{m2}$$

and

$$-\frac{\partial J}{\partial \nu} = \dot{\nu} = -(r)\nu .$$

Eliminating the co-state variable, solving for traded goods, and expressing the result in logs yields

(4) $$\log(m_1^*) = c_o + \frac{\beta_o}{\beta_1}\log(d^*) - \frac{1}{\beta_1}\log(p_{m1}),$$

where c_o contains the terms B_o, B_1, and β_1. U.S. agricultural import demand m_1^* from this country is the same as agricultural exports, which allows us to replace m_1^* by U.S. exports x_1. Since the budget constraint is presumed to hold at each instant in time, then in this model the foreign country's total exports are $x^* = e^* - d^* = \text{GDP} - d^*$. Interpreting e^* to be a country's earnings from domestic factors, i.e., GDP, we have

$$d^* = \text{GDP}^* - x^* .$$

The export demand equation (4) now becomes

(5) $$\log(x_1) = c_o + \frac{\beta_o}{\beta_1}\log(\text{GDP}^* - x^*) - \frac{1}{\beta_1}\log(p_{m1}),$$

where we refer to the term $\text{GDP}^* - x^*$ as the trade-adjusted GDP.

The stochastic version of the model leads directly to a stochastic estimating equation similar to (5). The stochastic version of Senhadji and Montenegro (1998) presumes that e^* follows an AR (1) process with unconditional mean $\bar{e}^*$ and unconditional variance $\sigma^2/(1-\rho)^2$, where σ^2 is the variance of the identically and independently distributed innovation ξ_t^*, and ρ determines the degree of persistence of the endowment shock at each instant in time. The scale parameters in (1) to (3) are specified as

$$B_j = Exp(b_j + \varepsilon_{j,t}), \quad j = 0,\ 1,\ 2,$$

where $\varepsilon_{j,t}$ are stationary shocks. In this case, the intercept term in (5) is

$$c_o = \ln\left(B_1 / B_o\right)/\beta_1 + (\varepsilon_{1,t} - \varepsilon_{o,t})/\beta_1 .$$

Drawing upon (5) for each category of U.S. commodity i exported to countries $k = 1,\ldots, K$,[5] our basic estimating equation is

(6) $$\ln x_{i,t}^{\text{US}} = \alpha_i + \beta_{1,i}\ln(XR_{i,t}) + \beta_{2,i}\ln\left[\sum_{k=1}^{K}\alpha_i^k(\text{GDP}_t^k - x_t^k)\right] + \bar{u}_{i,t}.$$

The dependent variable, $x_{i,t}^{\text{US}}$, is the total quantity of the ith agricultural commodity exported in period t, and $XR_{i,t}$ is the trade-weighted real exchange rate over all trading partners, $k = 1,\ldots,K$, importing this commodity. The second term is the weighted sum of the kth country's real GDP less its exports, where the weight α_i^k is the kth country's adjusted GDP share of all importing countries' total adjusted GDP. The construction and commodity-specific features of these variables are discussed in the next section. The parameters

[5] We switch from country index j to country index k to acknowledge that we are now working in a multi-country world rather than the simple theoretical world that we proposed above.

to be estimated are the intercept term α_i, the price elasticity term $\beta_{1,i}$ associated with the exchange rate, and the income elasticity term $\beta_{2,i}$. The price elasticity term is expected to be negative and the income term is expected to be positive. The nature of $\overline{u}_{i,t}$ is discussed below.

The current study attempts to contribute to the issue of causality by examining the contemporary relationships among exports, the trade-weighted real exchange rate, and the weighted sum of a country's real GDP (less its exports). In particular, this study adopts recent advances in time series modeling by specifying models based on a structural vector autoregression (VAR) approach. VAR econometric models impose as few *a priori* theoretical restrictions as possible to permit the regularities in the data to reveal themselves (Bessler 1984). Detailed derivations and summaries of VAR econometric models are provided by Sims (1980), Bessler (1984), Hamilton (1994), and Patterson (2000), and are not provided here. The VAR specification of equation (6) in lagged levels for the thirteen commodity/commodity groups is as follows:

$$x_{i,t}^{\mathrm{US}} = \sum_{i=1}^{l} C_i x_{t-i}^{\mathrm{US}} + BY_t + u_t \,, \tag{7}$$

where $x_{i,t}^{\mathrm{US}}$ is the total quantity of the ith agricultural commodity exported in period t, C_i is a coefficients matrix of lag length (l) to be estimated, Y_t is a matrix of exogenous variables, such as the trade-weighted real exchange rate over all trading partners and the weighted sum of the kth country's real GDP, B is an appropriately dimensioned matrix of coefficients to be estimated, the innovation term u_t is assumed to be white noise, where $E(u_t) = 0$, and

$$\sum_u = E(u_t u_t^{'})$$

is a positive definite matrix. The innovations u_t and u_s are independent for $s \neq t$. Although serially uncorrelated, contemporaneous correlation among the elements of u_t is possible.

Although Granger causality tests are widely used to assign causal direction, this approach has its limitations because it does not account for "indirect causal paths" (Granger and Newbold 1986, Hausman 2003). Recent works by Pearl (2000) and Hoover (2001) document alternative definitions of causality that extends the Granger–Sims causal definition. Spirtes, Glymour, and Scheines (2000) and Pearl (1995, 2000) propose directed acyclic graphs (DAG), a non-time sequence asymmetry in causal relations, as an alternative and more comprehensive approach for investigating causal relationships. Bessler and Akleman (1998) used (DAG) analysis procedures of Scheines et al. (1994) to optimally choose a set of causal relations on a structural VAR model. The application of DAG involves the theoretical work of Pearl (1995) and the algorithm (PC algorithm) in Spirtes, Glymour, and Scheines (2000). DAG analysis allows the construction of the data-determined orthoganization on contemporaneous innovation covariance (Swanson and Granger 1997) to assess the degree of interconnectivity and direction of causation (Awokuse and Bessler 2003, Bessler and Yang 2003, Babula, Bessler, and Payne 2004, and Babula et al. 2004). Our study focuses on illuminating the contemporaneous relationships among innovations (residuals). However, because of the limitations of the data to annual series, we cannot investigate the more dynamic aspects that would be present in quarterly or monthly data series.

The Data and Selected Properties[6]

We use annual data over the period 1970 to 2006.[7] To create a measure of the U.S. exchange rate associated with the export of the ith commodity in year t, we calculate $XR_{i,t}$ as a geometric exchange rate export-weighted index. The formula is

$$XR_{i,t} = Exp(\prod_{ikt} TW_{i,k} XRI_{k,t}) \,.^{8}$$

[6] See the Appendix for definition of variable construction.

[7] Because exports are lagged one year behind exchange rates and adjusted GDP, the actual time frame extends from 1970 to 2007, with exports extending from 1971 to 2007 and exchange rates and adjusted GDP extending from 1970 to 2006.

[8] Thus, the exchange rate is the average U.S. export-weighted index of foreign currencies. Since the composition of U.S. exports differs by commodity, each commodity faces a different exchange rate. For more details on exchange rates and access to commodity trade-weighted exchange rates maintained by the USDA's Economic Research Service, see www.ers.usda.gov/data/exchangerates/.

The export weights, $TW_{i,k}$, of the ith commodity for country k are fixed based on the average U.S. export share during the 1998–2000 period. The exchange rate index $XRI_{k,t}$ for the kth country is the real exchange rate, $XR_{k,t}$, defined as the product of the country's nominal exchange rate in local currency per dollar deflated by the ratio of the U.S. consumer price index to the country's consumer price index, and normalized to the year 2000:

$$XRI_{k,t} = XR_{k,t} / XR_{k,2000} .$$

Differences among the series can be seen by calculating the deviations from the mean of each series over the period 1970 to 2008. Figure 1 shows these differences for selected commodities. The overall pattern clearly reveals periods of depreciation following the first primary resource shock of the early 1970s, and the period of appreciation following the second oil shock in the late 1970s, early 1980s, and high real U.S. interest rates. The depreciation during the late 1980s is clearly evident, followed by some stability in the early 1990s, a period of relatively stagnant growth of the U.S. economy. Appreciation of the dollar started in about 1995, as the U.S. economy experienced total factor productivity (TFP) growth over the 1995–1999 period that exceeded by a factor of three the TFP growth of the previous two decades (Jorgenson 2001). Depreciation is apparent since about 2002.

While each sub-commodity series follows a similar depreciation-appreciation cycle, differences among them are apparent, with red meats standing out in recent years. As discussed below, differences in the estimated values of the exchange rate price elasticity, $\beta_{1,i}$ for each commodity, and the cycles of appreciation will both be seen to have important negative effects on commodity exports. In some years, these negative effects will dominate the effects of growth in adjusted GDP.

The United States exported agricultural commodities to over 183 countries during the 2001–2005 period. However, Table 1 shows that the bulk of these exports are concentrated in a small number of countries, thus giving them a relatively large weight in the calculation of the trade-weighted exchange rate During 2001–2007, 50 percent of total U.S. agricultural exports went to only four countries. While the concentration has increased for total U.S. agricultural exports, the major importing countries have changed. In 1976, ranked from highest to lowest, the major importing countries were Japan, the Netherlands, Germany, Canada, Korea, and India. In 2004, the major importers were Canada, Mexico, Japan, China, Korea, and Taiwan.[9]

Cotton and soymeal show some departure from the tendency for increased concentration. In the case of red meats, Japan and Canada account for over 50 percent of the total U.S. exports over the entire 1976–2005 period. The trade weights of these two countries thus dominate this commodity's trade-weighted exchange rate shown in Figure 1. It is this concentration that explains the distinct nature of this exchange rate compared with the others.

Next consider the association between the type of commodity exported and the income level of the importing countries. A clear difference exists between the GDP per capita of countries importing bulk commodities and those importing high value products. Bulk commodity exports are accounted for by largely middle income countries, while high value processed agricultural products tend to be exported to high income countries (Figure 2). The estimated exchange rate and income elasticities reported in the next section tend to correlate with this trade pattern. The exchange rate elasticities tend to be larger in absolute magnitudes for lower income countries than higher income countries, while the income elasticities tend to be larger for high income countries than low income countries.

Evidence from a battery of unit root tests conducted on the VAR models' endogenous variables in logged levels suggested that stationarity and cointegration were not an issue (Johansen and Juselius 1990, 1992). Harris (1995, pp. 27–29) and Kwiatkowski et al. (1992) discuss the well-known augmented Dickey Fuller (or ADF) test's tendency to indicate, falsely, nonstationarity particularly when, as in this study, samples are finite and when variables are stationary but have near-unit roots: that is, in the case where a series is

[9] This change in countries is consistent with the Diao, Roe, and Somwaru (2001) study of regional trade arrangements. They show that starting in about the early 1980s, growth of intra-NAFTA agricultural trade far exceeded the growth of world agricultural trade and the growth of NAFTA country trade with non-NAFTA countries.

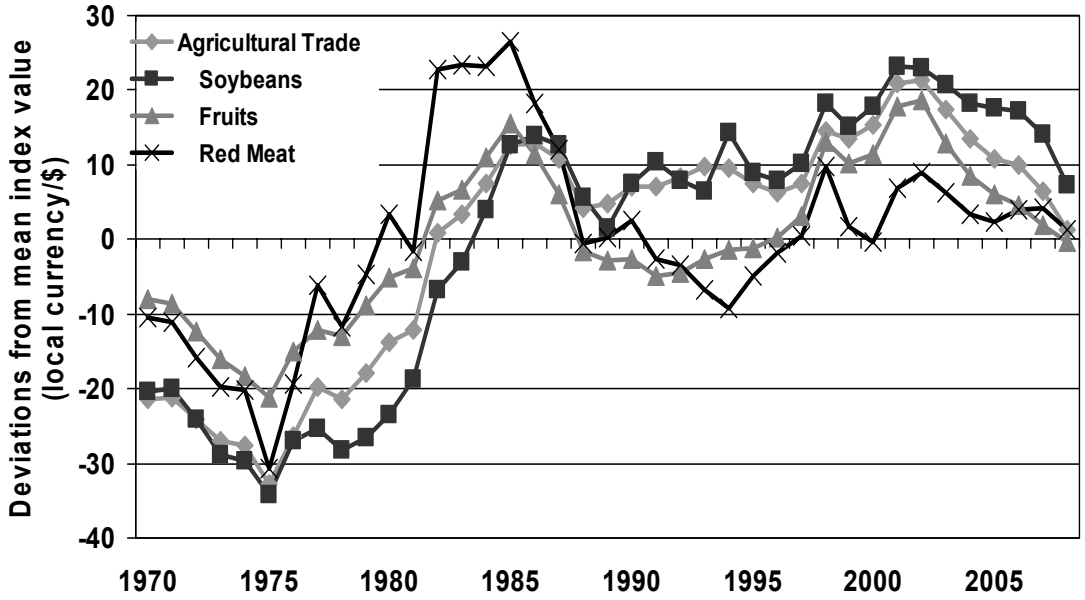

Figure 1. Deviations from Mean Real Trade-Weighted Exchange Rate Indices

Source: Shane (2008a).

Table 1. The Concentration of U.S. Agricultural Exports by Period (in number of countries)

	At Least 50% of Exports			At Least 75% of Exports		
Commodity	1976–80	1991–95	2001–07	1976–80	1991–95	2001–07
	(number of countries)					
Total agricultural exports	8	6	4	20	18	17
Corn	5	3	3	11	11	7
Cotton	3	4	4	7	10	8
Rice	5	8	5	12	19	14
Tobacco	5	4	6	13	11	15
Wheat	7	6	7	18	13	18
Soybeans	3	5	3	9	9	7
Soymeal	4	6	5	9	12	13
Soyoil	4	5	6	9	9	13
Fruits	3	2	3	8	6	8
Vegetables	4	2	2	13	10	7
Red Meats	1	1	2	3	2	3
Poultry	6	4	3	11	7	12
Average	4.5	4.3	4.1	11.0	10.5	10.9

Source: Calculated from the U.S. Agricultural Trade Database, Economic Research Service, U.S. Department of Agriculture (see www.ers.usda.gov/data/FATUS).

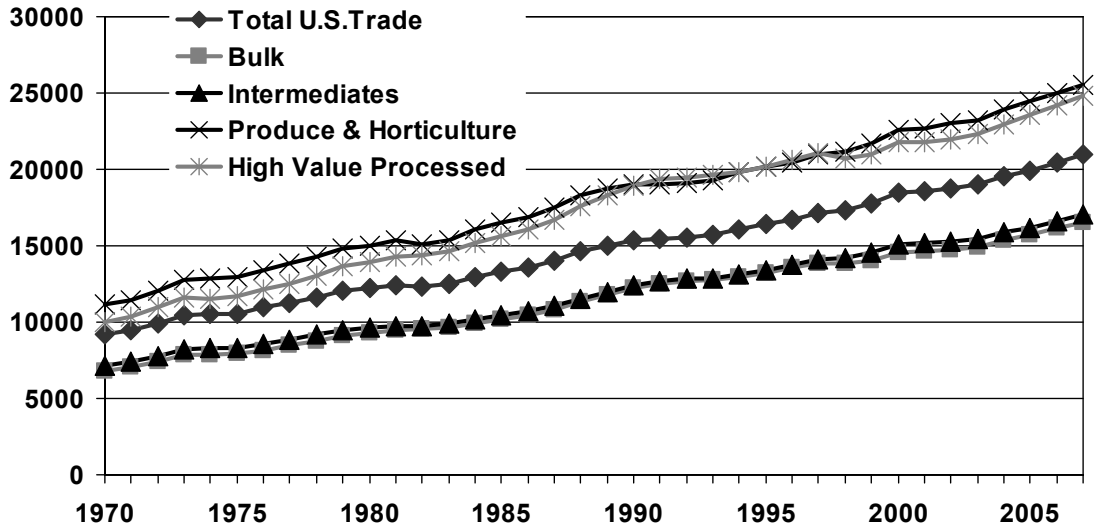

Figure 2. Trade-Weighted per Capita Income of U.S. Agricultural Importing Countries by Category of Inputs (1970–2007)

Source: Shane (2008b).

"almost nonstationary."[10] In such cases, ADF-type unit root tests often fail to reject the null hypothesis of nonstationarity. An accepted procedure in this case has been to treat the variables as stationary without differencing them (Harris 1995, pp. 27–29, Kwiatkowski et al. 1992, and Babula, Bessler, and Payne 2004, p. 6). When evidence from the ADF test suggested that evidence was sufficient to reject the null hypothesis of nonstationarity, we concluded that the variable was likely stationary. We employed the Kwiatkowski et al.'s test (hereinafter called the KPSS test) for the presence of unit roots. The KPSS test results indicate that all series are stationary or integrated of order 0. (The ADF and KPSS tests are not reported. Readers interested in such information may contact the authors for these tests.)

We apply *PC algorithm* (Spirtes, Glymour, and Scheines 2000) to observational data for capturing directed acyclic graphs. PC algorithm is available as the software TETRAD III (Scheines at al. 1994).

[10] For details on the Dickey-Fuller and the augmented Dickey-Fuller tests, see Fuller (1976), Dickey and Fuller (1979), and test procedure summaries in Hamilton (1994) and Patterson (2000).

Results

The results based on estimating the parameters of equation (7) for the selected commodities are reported in Table 2. The exact estimated form of the export equations depends on the specific commodity (see column 4 of Table 2). Since our estimated models contain lagged dependent variables as control variables and include higher-order ARMA specifications, we use the Marquardt nonlinear least squares algorithm (see Davidson and MacKinnon 1993, pp. 329–341, and Greene 1997, pp. 600–607). Note that the nonlinear least squares estimates are asymptotically equivalent to maximum likelihood estimates and are asymptotically efficient.

Overall, the results show strong evidence of a significant link between total U.S. agricultural exports, and the trade-weighted exchange rate and trade-adjusted real income. The estimated standard error of the income elasticity of total agricultural export equation is significant at the one percent level. The error associated with the exchange rate elasticity is significant at the 10 percent level. A similar pattern holds for eight of the twelve commodity sub-categories. The sign of the income term is positive as expected and significant for all commodities. The sign of the ex-

Table 2. Estimation Results of U.S. Agricultural Exports, Real Exchange Rate, and Weighted GDP

Variable	Intercept	Exchange Rate	GDP	ARIMA	R^2	Durbin-Watson
Total agricultural exports	6.428	-0.507	0.751	[0,1,(1,2,3,4)]	0.918	1.956
	0.742***	0.341*	0.230***	1.024		
				0.101***		
				0.943		
				0.151***		
				1.027		
				0.091***		
				0.969		
				0.026***		
Corn exports	7.187	-1.297	0.976	(0,0,1)	0.588	1.936
	0.771***	0.636**	0.289***	0.606		
				0.131***		
Cotton exports	2.994	-0.867	1.792	(1,1,1)	0.562	1.945
	0.886***	0.602	0.666**	0.088		
				0.315		
				0.466		
				0.277*		
Rice exports	4.115	-0.251	0.955	(0,0,1)	0.659	1.981
	0.449***	0.341	0.324***	0.391		
				0.161***		
Soybean exports	5.627	-0.196	0.718	(1,1,2)	0.814	1.917
	0.733***	0.293	0.268***	0.082		
				0.205		
				1.054		
				0.083***		
				0.893		
				0.0051***		
Tobacco leaf exports	7.633	-0.543	-0.339	(0,0,2)	0.774	2.154
	0.351***	0.196***	0.135***	0.562		
				0.178***		
				0.093		
				0.186		
Wheat exports	7.281	-1.291	0.967	(0,0,1)	0.431	1.987
	0.449***	0.559***	0.396***	0.659		
				0.123***		
Soymeal exports	5.324	-0.865	1.221	(0,0,2)	0.461	2.061
	0.433***	0.335***	0.392***	0.374		
				0.176***		
				0.175		
				0.178		
Soyoil exports	6.145	-0.751	0.486	[(1,2),1,(7,11)]	0.567	1.799
	0.266***	0.519*	0.343*	0.078		
				0.174		
				-0.516		
				0.167***		
				-0.903		
				0.031***		
				-0.043		
				0.0.44		

cont'd.

Table 2 (*cont'd.*)

Variable	Intercept	Exchange Rate	GDP	ARIMA	R^2	Durbin-Watson
Fresh fruit exports	3.289	-0.682	1.465	[0,0,(1,2)]	0.937	1.836
	0.630***	0.349***	0.178***	0.798		
				0.157***		
				0.559		
				0.169***		
Fresh vegetable exports	0.834	-0.547	2.189	[1,1,(1,2,3,4)]	0.933	2.095
	3.269	0.766	1.069***	0.744		
				0.156***		
				0.374		
				0.208***		
				0.059		
				0.227		
				0.469		
				0.168***		
				0.628		
				0.153***		
Poultry exports	-7.196	-0.390	5.251	[1,1,(1,2,3)]	0.980	1.834
	1.495***	0.359*	0.685***	1.337		
				0.178***		
				1.069		
				0.241***		
				0.476		
				0.189***		
Red meat exports	-8.286	-0.656	4.651	[(1,4),1,1)]	0.985	1.933
	0.835***	0.362**	0.166***	0.621	0.918	
				0.138**		

Note: *,**, and *** indicate statistically significant at the 10 percent, 5 percent, and 1 percent level, respectively.

change rate term, as expected, is negative in all equations and significant in eight of the thirteen commodity categories.

The estimated income elasticity for total agricultural exports is 0.75, while the estimate of the exchange rate elasticity is -0.51 (Table 2). Commodity-specific income elasticities range from 5.25 for poultry exports to about 0.72 for soybeans. Exchange rate elasticities range from a high of about -0.2 for soybeans to a low of -1.3 for corn and wheat. Seven of the twelve commodities have income elasticities larger than the absolute value of their corresponding exchange rate elasticities.

Notice that the income elasticities reported in Table 2 appear to be linked to the income level of countries. The income elasticities for the high value near consumer-ready products such as red meats, poultry, fresh fruits, and vegetables that Figure 2 shows are more likely to be exported to higher income countries and to have larger income elasticities than do the bulk commodities (e.g., corn, rice, and wheat), which tend to be exported to lower income countries. Thus, equal growth in income across countries will tend to have a larger effect on exports of high value agricultural products than on the exports of bulk commodities. The absolute value of the estimated exchange rate elasticities for the two major bulk commodities, corn and wheat, is larger than the estimated exchange rate elasticity for total agricultural exports. This result suggests that appreciation of the dollar in low income countries can have major negative effects on growth in the export of these bulk commodities, the estimated magnitudes of which we discuss in the next section.

Testing for Contemporaneous Causality Using DAG

Following Bessler and Yang (2003) and Awokuse and Bessler (2003), DAGs were used to capture the causal glow among exports, exchange rate, and GDP. The PC algorithm checked for both unconditional and conditional correlations between the variables to determine the correlations and the order among the variables. The TETRAD III program was applied to the data to determine the direction of the causal flow of information between variables. Its search algorithm reveals that the exchange rate and GDP are direct and contemporaneous causes of exports as follows:

$$\text{Exchange rate} \rightarrow \text{Exports} \leftarrow \text{GDP}.$$

This suggests that equation (7) for all the commodities/group of commodities follows a causal inverted fork. For robustness of the outcomes, we consider various levels of significance in determining the causal structure of the variables. The results reported are at 30 percent significance level for the removal of directed edges between the variables. This implies that the correlation and conditional correlation between two variables must be significantly different from zero at the 30 percent significance level (directed edges between exchange rate and exports and GDP and exports).

Decomposing Exchange Rate and Income Effects on Agricultural Exports

To show the effects of income and exchange rates on exports over time, we calculate the contribution of the exchange rate and adjusted GDP variables to predicted exports based upon the estimated parameters reported in Table 2. The basic form of the calculation is

$$\frac{\dot{\hat{X}}}{\hat{X}} = \hat{b}\,\frac{\dot{\text{GDP}}}{\text{GDP}} + \hat{c}\,\frac{\dot{Ex}}{Ex},$$

where, for the ith commodity,

$$\frac{\dot{Ex}}{Ex} = (XR_{i,t+1} - XR_{i,t}) / XR_{i,t}$$

and

$$\frac{\dot{\text{GDP}}}{\text{GDP}} = \begin{bmatrix} \sum_{k=1}^{K} \alpha_i^k (\text{GDP}_{t+1}^k - x_{t+1}^k) \\ -\sum_{k=1}^{K} \alpha_i^k (\text{GDP}_t^k - x_t^k) \end{bmatrix} / \sum_{k=1}^{K} \alpha_i^k (\text{GDP}_t^k - x_t^k).$$

The results of these calculations appear in Figure 3 for total agricultural exports. The results for all commodities appear in Table 3 for yearly averages over the period 1972–2003.

The first two bars of Figure 3 show, respectively, the effects of annual rate of change in the exchange rate and trade-adjusted GDP on the predicted growth in total agricultural exports, which is shown by the third bar. In 31 of the 35 years reported, growth in trade-adjusted GDP had a positive effect on growth in U.S. agricultural exports. In 19 of these years, the change in the exchange rate had a negative effect. In eight of these years, the negative exchange rate effect dominated the positive GDP effect, causing a negative rate of growth in agricultural exports. On a more periodic basis, it can be seen that the growth in trade partner trade-adjusted GDP was the main impetus for growth in total U.S. agricultural exports over the period 1972 to the early 1990s. Another feature is the appreciation of the trade-weighted U.S. exchange rate, which had a negative effect on growth in total exports in 12 of the 21 years 1972–1993, and almost always tended to counter the positive effects of income growth on exports. Between 1997 and 2002, the appreciation of the dollar appears to be a major contributor to a generally negative rate of growth in U.S. agricultural exports. The depreciation of the exchange rate during 2003 to 2005 had a stronger effect on the increase in growth of exports than growth in trade partner trade-adjusted GDP.

The results appear to support Schuh's (1974) argument that the early 1970s boom in U.S. agricultural exports was caused by a depreciating dollar, particularly for the year 1974, although growth in trade-adjusted GDP appears to have accounted for an even larger positive effect on exports. The U.S. adjustment to the second major oil shock at the beginning of the 1980s entailed a rising real U.S. interest rate, a decline in import demand, and stagnant growth in many external debt impacted developing countries. During 1980–1984, the appreciating value of the dollar outweighed the more modest effects of growth in trade partner income. The result was negative growth in total U.S. agri-

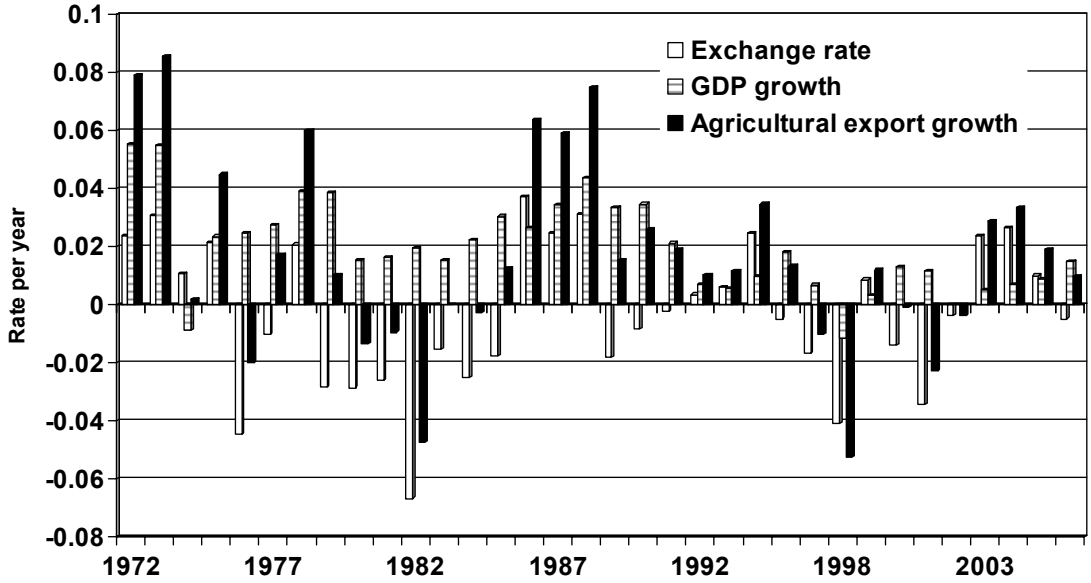

Figure 3. Total Agricultural Exports: Effects of Exchange Rate and Trade Partner Adjusted GDP on Growth in Predicted Exports

cultural exports (see Table 3, column 3). In the late 1980s, and prior to the financial crises faced by many developing countries in the early 1990s, both a depreciating dollar and income growth helped lift the growth of U.S. agricultural exports.

For 1990–2006, the results suggest that in spite of relatively rapid economic growth for many of the world's economies, the trade-adjusted income growth in U.S. agricultural trade partners tended to have small positive, and sometimes negative, effects on U.S. agricultural exports, with the devaluing dollar playing a dominant role in recent years.

We next focus on the twelve sub-commodity categories and discuss the degree to which they depart from the features shown for total agriculture.

Commodity Specific Effects

Table 3 shows that the annual average effect of exchange rate appreciation on exports was negative for all commodities for the 1980–1984 period and for about nine of the twelve commodities over the 1990–2004 period. A distinguishing feature of these periods is that the negative exchange rate effect tended to dominate the positive income growth effect for the major bulk commodities, corn and wheat, but not for the high value commodities. Another feature is that positive income effects on growth in exports tended to fall for all commodities starting in 1995. Moreover, this decline tended to exceed the decline in the income effect for total agricultural exports for the bulk commodities, while the decline for the higher value commodities was less severe.

The domination of an appreciating trade-weighted exchange rate over income growth on U.S. commodity exports is most pronounced for corn and wheat. The negative effect of an appreciation of wheat's trade-weighted exchange rate dominated the positive income effect on average for the periods 1980–1994 and 2000–2004 (Table 3).

We noted above that high value products tend to be exported to higher income countries, and their estimated income elasticities tend to be larger than elasticities for bulk commodities. The results reported in Table 3 for fresh fruit, fresh vegetables, poultry, and meat show that from 1972 to 1989, the effect of growth in trade partner income on the exports of these higher value commodities tends to be larger than are the same effects for the bulk commodities. An example is the

Table 3. Effects of Trade-Weighted Exchange Rate and Trade Partner Trade Adjusted GDP on Predicted U.S. Agricultural Exports

	Average Rate per Year							
TOTAL AG. EXPORTS	1972–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2006
Exchange rate	0.018	0.000	-0.033	0.010	-0.006	-0.006	0.000	0.003
Income	0.047	0.021	0.021	0.032	0.020	0.297	0.007	0.012
Total effect	0.065	0.021	-0.012	0.041	0.013	0.291	0.007	0.014
Corn								
Exchange rate	0.042	0.004	-0.068	0.027	-0.022	-0.033	-0.020	0.05
Income	0.065	0.028	0.030	0.043	0.029	0.006	0.006	0.01
Total effect	0.107	0.032	-0.038	0.070	0.007	-0.027	-0.013	0.063
Cotton								
Exchange rate	0.028	0.003	-0.045	0.018	-0.015	-0.022	-0.013	0.034
Income	0.114	0.063	0.055	0.070	0.055	0.015	0.020	0.014
Total effect	0.142	0.065	0.009	0.089	0.040	-0.007	0.007	0.047
Rice								
Exchange rate	0.009	0.003	-0.013	-0.006	-0.012	-0.003	-0.004	0.011
Income	0.059	0.028	0.026	0.039	0.024	0.006	0.007	0.012
Total effect	0.067	0.031	0.013	0.033	0.012	0.003	0.004	0.022
Soybean								
Exchange rate	0.009	0.001	-0.015	0.005	0.001	-0.007	0.000	0.006
Income	0.043	0.020	0.019	0.030	0.021	0.008	0.007	0.007
Total effect	0.052	0.021	0.005	0.035	0.022	0.000	0.008	0.012
Tobacco leaf								
Exchange rate	0.033	0.025	-0.037	-0.013	0.006	-0.012	-0.003	0.029
Income	-0.019	-0.008	-0.008	-0.013	-0.008	-0.002	-0.001	-0.001
Total effect	0.015	0.017	-0.044	-0.027	-0.003	-0.014	-0.004	0.028
Wheat								
Exchange rate	0.009	-0.004	-0.019	-0.022	-0.029	0.010	-0.007	0.020
Income	0.015	0.007	0.007	0.010	0.007	0.002	0.002	0.003
Total effect	0.024	0.003	-0.012	-0.012	-0.023	0.012	-0.005	0.023
Soymeal								
Exchange rate	0.018	-0.008	-0.038	-0.045	-0.059	0.020	-0.014	0.040
Income	0.066	0.040	0.033	0.049	0.027	0.014	0.020	0.019
Total effect	0.084	0.033	-0.005	0.005	-0.032	0.034	0.006	0.060
Soyoil								
Exchange rate	0.008	-0.021	-0.048	-0.021	-0.049	-0.009	-0.014	0.030
Income	0.025	0.022	0.021	0.032	0.026	0.027	0.017	0.004
Total effect	0.033	0.001	-0.027	0.011	-0.022	0.018	0.003	0.034
Fresh fruit								
Exchange rate	0.026	-0.004	-0.034	0.019	0.005	-0.019	-0.004	0.021
Income	0.091	0.043	0.040	0.059	0.033	0.009	0.014	0.015
Total effect	0.116	0.039	0.006	0.079	0.038	-0.010	0.011	0.037
Fresh vegetables								
Exchange rate	0.017	-0.004	-0.013	0.010	-0.003	-0.020	0.003	0.029
Income	0.128	0.070	0.054	0.086	0.032	0.013	0.038	0.027
Total effect	0.145	0.066	0.040	0.096	0.028	-0.007	0.041	0.056
Poultry								
Exchange rate	-0.006	-0.029	-0.041	-0.008	-0.027	0.065	-0.005	0.015
Income	0.307	0.171	0.151	0.187	0.082	-0.011	0.046	0.010
Total effect	0.301	0.142	0.109	0.179	0.055	0.054	0.042	0.025
Red meat								
Exchange rate	0.029	0.001	-0.049	0.031	-0.011	0.011	0.001	0.023
Income	0.308	0.129	0.138	0.200	0.130	0.024	0.030	0.057
Total effect	0.337	0.130	0.089	0.231	0.120	0.035	0.031	0.080

Source: Calculated based on the elasticities appearing in Table 2 and the data.

case of red meat exports compared to the major bulk commodities. The absolute value of the exchange rate elasticity is smaller for red meat than for corn and wheat, while the income elasticity for red meat is larger than for these commodities. Corn and wheat tend to be exported to countries whose per capita incomes are lower than countries importing red meat. While the exports of both of these commodities were negatively affected by exchange rate appreciation, red meat exports were affected negatively only in two periods, neither of which dominated the effect of income growth.

Conclusions

The real trade-weighted exchange rate and trade partner income are shown to be key determinants of U.S. agricultural exports. The data clearly show the evolution of the real trade-weighted exchange rate to vary by commodity, although general similarities of appreciation and depreciation are evident. The trade data also suggest that bulk commodities tend to be exported to lower income countries than do the higher value commodities such as fresh fruit and red meat. For the period 1970–2006, a one percent annual increase in trade partners' income is found to increase total agricultural exports by about 0.75 percent, while a one percent appreciation of the dollar relative to trade partners' real trade-weighted exchange rate decreases total agricultural exports by about 0.51 percent. The net effect on total agricultural exports depends on the magnitude of growth in income compared to the magnitude of change in the trade-weighted exchange rate.

These effects are also found to carry over to 12 commodity subcategories, although the effects are conditioned by differences between bulk and high value commodities. The estimated income elasticities for commodity subcategories tend to be larger in magnitude than the absolute value of the exchange rate elasticities. Furthermore, the income elasticities for the high value products, such as red meats, poultry, fresh fruits, and vegetables, tend to be larger than the elasticities for bulk commodities. Growth in incomes has a larger effect on exports of high value agricultural products than on bulk commodity exports.

The contemporary relationships among exports, the trade-weighted real exchange rate, and the weighted sum of a country's real GDP were investigated by applying the directed acyclic graphs (DAG) technique. We find that GDP and exchange rate depict an inverted fork causal relationship with exports.

We also find from a decomposition analysis that the negative effect of exchange rate appreciation on exports often dominates the positive effect from income growth. Most of the historical increases in agricultural exports are associated with income growth, whereas most of the declines in exports are associated with an appreciation of the U.S. trade-weighted exchange rate. This analysis also shows that the income effect has tended to dampen over time. This dampening effect has allowed the appreciation of the exchange rate to dominate the income effect, particularly for the bulk commodities. This dampening effect has been less severe for the higher value commodities.

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Appendix

Data Sources

The data underlying this paper come from the ERS Exchange Rate Data Set, the International Macroeconomic Data Set, and the Foreign Agricultural Trade of the United States (FATUS) Data Set—all available on the ERS website (www.ers.usda.gov). The base data are collected from four primary sources—the Food and Agricultural Organization of the United Nations (FAO Stat), the International Financial Statistics of the International Monetary Fund (IFS), the World Development Indicators of the World Bank (WDI), and the Federal Reserve Board's International Statistics (FRBFS)—as well as from a number of private vendors such as Oxford Economic Forecasting, Inc., and Global Insight. The resulting ERS data involve substantial transformation and filled-in values developed by the Economic Research Service. The data in the paper cover the period 1970–2007, but because of lags, only 37 yearly observations were utilized for the estimations of total U.S. agricultural exports and twelve U.S. agricultural export commodities.

The data used to construct the

$$x_{i,t}^{\mathrm{US}},\ XR_{i,t},\ \text{and}\ \sum_{k=1}^{K}\alpha_i^k \mathrm{GDP}_{i,t}^k - Ex_{i,t}^k$$

were derived from FATUS, FAOStat, the ERS Exchange Rate Data Set, and the background tables of the ERS International Macroeconomic Data Set (www.ers.usda.gov/data/macroeconomics/). The trade-weighted exchange rates were taken from the ERS Exchange Rate Data Set (www.ers.usda.gov/data/exchangerates). The GDP series were taken from the ERS International Macroeconomic Data Set Background Tables (www.ers.usda.gov/data/macroeconomics). Total exports of goods and services subtracted from GDP were obtained from WDI and filled in with numbers from Global Insight. The weights used in the transformations were taken from the Exchange Rate Data Set. The export data were taken from the ERS Foreign Agricultural Trade of the United States (FATUS) Data Set and FAOStat.

Total U.S. agricultural exports values in current dollars were adjusted by the FAO unit value index to obtain a real U.S. agricultural export series. The export series for the commodities were the quantity of exports in metric tones. The adjusted GDP series involved subtracting total real exports from real GDP, both measured in 2000 $. Both the total real exports and real GDP series were taken from WDI. We convert the country current price series to a year 2000 base by dividing the series by the year 2000 number. This converts the year 2000 index to 100. The constant country value of export and GDP series are then divided by their respective 2000 base price indexes. Finally, the country real value of export and GDP series are converted to dollars with a fixed year 2000 exchange rate that converts local currencies into dollars. The adjusted country totals were then averaged using the same trade-weights used to derive the commodity real exchange rates. The country coverage was limited to 80 major export destinations for U.S. exports used in the ERS Exchange Rate Data Set. You can find both the country coverage and the weighting scheme at the ERS website referred to above.