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Rising Global Food Prices and Price Variability: A Blessing or a Curse for Global Food Supply?

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Abstract

This study examines the response of global aggregate acreage of selected crops to international prices and price variability. Applying up-to-date panel data econometric techniques, the study addresses whether the recent rise in international food prices is a blessing or a curse to the global supply of four key staple crops: wheat, corn, soybeans, and rice. The results reveal that rising own crop prices spur an increase in the worldwide aggregate acreage of these crops, whereas higher competing crop prices have the opposite effect. These results are robust across different types of panel data econometric estimators as well as the use of either future or spot prices. Our preferred acreage supply model specification further shows that fluctuations of own crop prices have a statistically significant negative (positive) effect on acreages of wheat (soybeans), but insignificant effects on acreages of corn and rice.

Résumé

Cette étude examine la réaction de la superficie totale mondiale d'un certain nombre de plantes à aux prix internationaux et à leur variabilité. En appliquant les techniques de pointe en économétrie des données de panel, l'étude s'interroge si la récente hausse des prix internationaux des denrées alimentaires est une bénédiction ou une malédiction pour l'offre mondiale de quatre cultures de base: le blé, le maïs, le soja et le riz. Les résultats révèlent que les superficies globales des cultures en question réagissent positivement à la hausse de leur propre prix et négativement à celle des prix des cultures concurrentes. Ces résultats sont robustes à l'utilisation de différents types d'estimateurs économétriques ainsi qu'à l'utilisation des prix futurs ou comptant. Notre modèle préféré montre que les fluctuations des prix des cultures ont un effet négatif (positif) statistiquement significatif sur les superficies de blé (soja), mais négligeables sur les superficies de maïs et de riz.

1. Introduction

In recent decades, the world has experienced significant land use changes, including diminished arable land, deforestation and land degradation, expansion of urban areas, and use of land for biofuel production. These dynamics have implications for feeding the world's population, which is predicted to increase by a further 50 percent by 2050; specifically, the allocation of scarce land resources for cropland is of vital concern. The recent increase in global agricultural commodity prices, and the subsequent food versus biofuel trade-offs, has made the food security situation even more challenging. Empirical evidence shows that several countries have responded to higher crop prices by shifting land away from forest and pasture to be used for planting crops (Timilsina et al., 2012).

The literature on the estimation of supply response to prices has a long history in agricultural economics (Nerlove, 1956; Lee & Helmberger, 1985). Nevertheless, there are various reasons to reconsider this research. The majority of the previous empirical literature studied supply response at either a country or a regional level. The effect of price risk is usually thought of as a microeconomic problem for producers; however, several factors, such as foreign direct investment in agriculture, make global-level agricultural production equally sensitive to prices and their volatility. Given that previous analyses at the micro-level showed the supply effects of output price and price risk at the micro and national levels (Newbery & Stiglitz, 1981; Binswanger & Sillers, 1983; Fafchamps, 1992), this study addresses whether this effect ensues at the global scale as well.

Another reason for the renewed research interest in the topic is growing biofuel demand and the financialization of agricultural commodities, both of which are alleged to have contributed to the world's high and volatile food prices. This paper focuses on the global responsiveness of arable land conversion to price changes and price variability for four key crops: wheat, corn, soybeans, and rice. We provide a global acreage elasticity of prices that may serve as an indicator of how major agricultural commodity producers respond to high food prices and volatility.

The econometric approach is in line with a partial supply adjustment framework updated with dynamic response, alternative price expectation assumptions, and introduction of price risk variables. The study applies state-of-the-art panel econometric methods to estimate global acreage response equations for the aforementioned four agricultural commodities. These commodities play a crucial role in both global supply and global demand. They are also partly substitutable in production and in consumption. Together, these crops comprise three-quarters of global calorie content (Roberts & Schlenker, 2009). The use of corn, soybeans, and wheat as feed for livestock and dairy purposes has also grown due to growing demand for meat as a result of fast economic growth in emerging and developing economies. The rapidly growing market for biofuels constitutes another source of demand for corn. These four crops make up a sizable share of global area and production. Corn, wheat, and rice, respectively, are the three largest cereal crops cultivated around the world. According to data from FAO (2012), these crops accounted for more than 75 percent and 85 percent of global cereal area and production in 2010, respectively. Soybeans contribute about one-third of both the global area and production of total oil crops.

Using panel data from 1992 to 2010, this study estimates the response of global acreage to output and input prices, and to output price variability. Because expected prices are unknown at time of planting, we proxy farmers' price expectations using planting season spot and futures prices. We use international prices, rather than local farm gate prices, to proxy farmers' price expectations because several empirical studies indicate large transmission elasticities between international and domestic prices (Minot, 2010; Greb et al., 2012). Using international instead of domestic output and input prices also circumvents potential reverse causality from area or yield to prices since individual economies are more likely to be price takers in the global output and input markets. At the same time, the prices relevant to producers when they are forming harvest-period price expectations are country-specific, in accordance with the planting patterns of each country. As a result, we use country-specific spot and futures prices based on crop calendars of each country.

The rest of the paper is organized as follows. The following section presents a brief overview of global acreage and output price trends. Section 3 provides the theoretical framework and a review of recent literature. The empirical framework follows in section 4, where we discuss the econometric methods and data used in this study. Section 5 presents and discusses the results, and the last section concludes.

2. Global Acreage and Price Trends

2.1 Acreage Trends

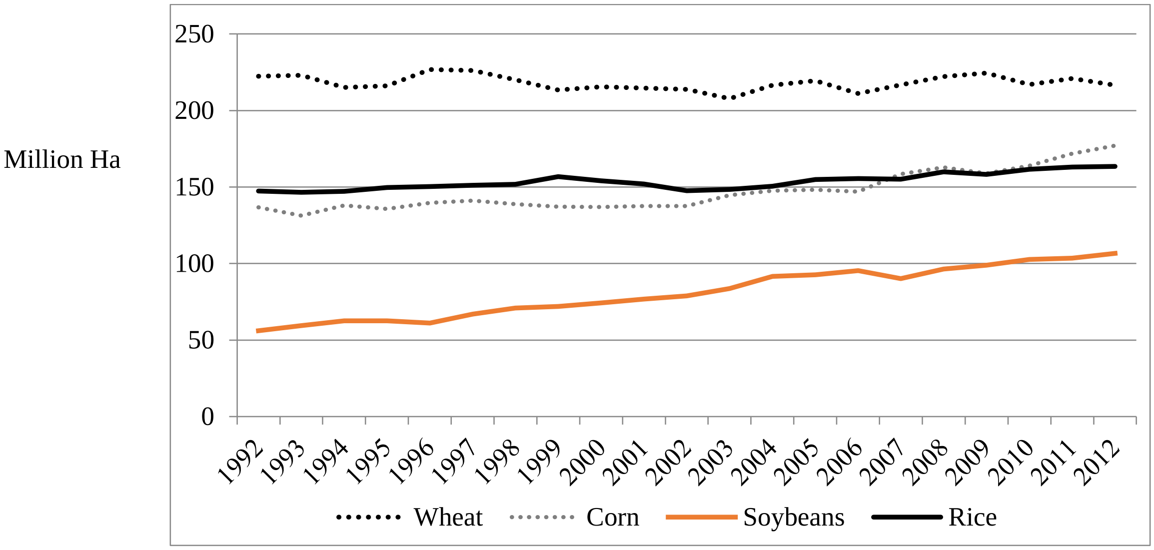
Agricultural productivity and competition for land are major drivers of global food production (Smith et al., 2010). Since the beginning of human history, there have been land cover changes involving clearing of natural ecosystems for agriculture, pasture, urbanization, and other purposes. Total cropland constituted less than one-tenth of the global land cover in the 18th century (Beddow et al., 2010), whereas about one-third of the global land area is currently devoted to agricultural use (Hertel, 2011).

Cropland expansion and increased productivity are key to boosting agricultural production in order to feed the growing world population. In South and East Asia, the Middle East, North Africa, and many advanced economies, area expansion has limited potential to increase food production; however, there is substantial potential for area expansion to increase crop production in many other regions such as Africa south of the Sahara, Latin America, and the Caribbean (Bruinsma, 2003). The recent rise in agricultural commodity prices has also resulted in more competition for agricultural land. For instance, there have been large foreign agricultural investments in several developing countries, primarily focusing on growing high-demand crops like corn, soybeans, wheat, rice, and other biofuel crops (von Braun & Meinzen-Dick, 2009).

Figure 1 shows that, to varying degrees, global acreage has increased for corn, soybeans, and rice over the past 20 years, with significant expansion for soybeans and corn. Global wheat acreage has been more or less stable over this period. Comparing the 1992–2000 and 2001–2010 periods reveals that aggregate global acreage of the four crops increased by close to 10 percent between these two periods. The majority of this acreage increase (about 40 percent and 15 percent, respectively) came from expansion of land for soybean and corn production. Global rice acreage also saw growth of about 3 percent, but there was a small (1 percent) decline in global wheat acreage during this period.

Some studies indicate that emerging biofuel markets and Chinese soybean imports are the major drivers of the acreage increases for corn and soybeans (Abbott et al., 2011). Acreage of these crops has been increased by both adding marginal land into cultivation and bidding land away from low-demand crops. To this end, a recent study has shown that over one-quarter of the increase in the area of high-demand crops between 2004-2005 and 2010-2011 came from displaced low-demand crop area, whereas the rest came from the expansion of marginal land (Haile et al., 2013).

Figure 1. Global acreage trends



Source: FAO STAT (2012)

Table 1 shows the size and the average percentage change of acreage between the 1990s and the 2000s. In line with the global changes described previously, globally aggregated acreage in the top six cultivating countries has seen the largest expansions for soybeans, followed by corn and rice. In contrast, global wheat land was lower in the 2000s in all of the top cultivating countries. Area allocated to soybeans and rice was higher for all six top producer countries in the 2000s compared to the 1990s. The same is true for corn, with the exception of Mexico and the EU. No African country is among the top six cultivating countries of any of these four crops; as there is marginal land available for cultivation in Africa south of the Sahara, this may be indicative of potential acreage expansion in order to improve food production in the region.

2.2 Price Dynamics

Although global acreage of most crops has increased in recent decades, the changes have not always been smooth upward trends. Several factors play a role in such inter-annual variations. This study examines how acreages of four staple food commodities have changed as a response to changes in international prices and price volatility. The study involves cross-country panel data and recent developments in panel econometrics to test for several hypotheses on cropland adjustments to prices and volatility. While previous literature indicates that the volatility of agricultural commodity prices has shown a similar development during this period (e.g. Sumner, 2009; Huchet-Bourdon, 2011), it is worthwhile to empirically investigate whether price volatility is actually one of the key factors behind these acreage variations.

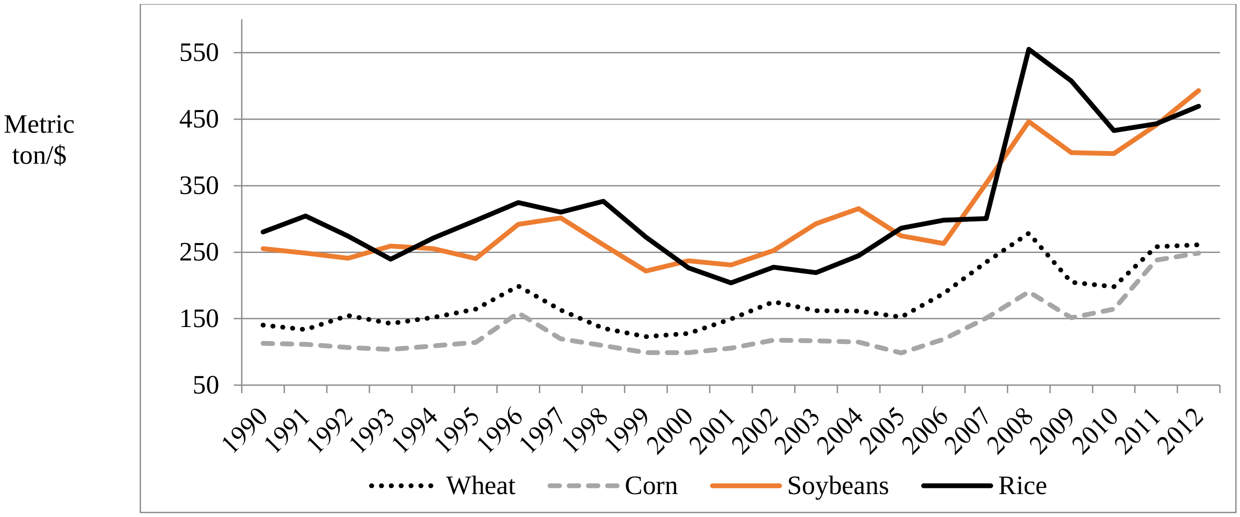
Agricultural investment has been limited since the early 1970s; this trend has been attributed to prevailing low international agricultural commodity prices. However, agricultural commodity prices have shown dramatic upward movement since the middle of the previous decade (Figure 2). High food prices provide incentives for net food sellers to produce more food. Whenever agricultural output prices are on an upward trend relative to input prices, farm income grows, encouraging agricultural investment. Price volatility, however, presents a challenge for producers, and evidence shows that the recent increase in price trends is associated with higher volatility (Gilbert & Morgan, 2010). Volatility introduces risks that affect the investment decisions of risk-averse farmers (von Braun & Tadesse, 2012).

Table 1. Acreage of the six largest cultivating countries (in 2010), average-1990s versus 2000s

Crop	Country	Area (Million Ha)		
		1991-2000	2001-2010	% Δ
Wheat	India	63	27	-57
	EU	121	26	-79
	China	106	23	-78
	USA	64	20	-69
	Russian Federation	36	24	-34
	Australia	18	13	-28
	Top six Total	407	133	-67%
Corn	USA	28	31	7%
	China	23	28	19%
	Brazil	12	13	3%
	India	6	8	24%
	Mexico	8	7	-4%
	EU	9	9	-1%
	Top Six Total	87	95	9%
Soybeans	USA	26	30	13%
	Brazil	11	20	76%
	Argentina	6	14	132%
	India	5	8	57%
	China	8	9	11%
	Paraguay	1	2	142%
	Top Six Total	58	83	44%
Rice	India	43	43	0%
	China	32	29	-8%
	Indonesia	11	12	7%
	Bangladesh	10	11	6%
	Thailand	9	10	12%
	Myanmar	6	7	31%
	Top Six Total	111	113	1%

Source: Data from FAO STAT (2012) and national sources
Notes: EU refers to the 27 European countries and the production and area size refer to the period average of aggregated amount in these countries.

Figure 2. International cash prices for selected agricultural commodities

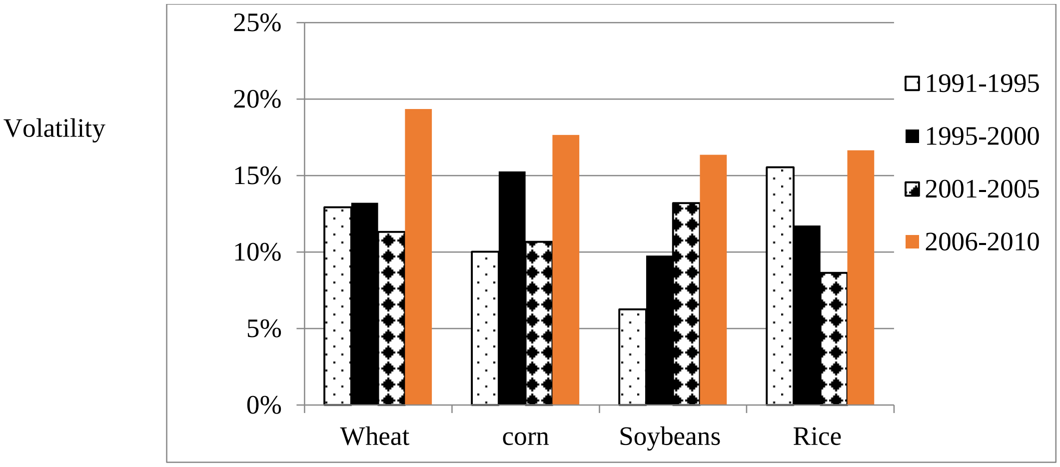


Source: World Bank price database

Since agricultural producers in many developing countries are neither able to deal with nor be protected from the consequences of price risk, they are substantially exposed to the effects of international agricultural market price instability.

Price volatility of our selected crops, as measured by the moving standard deviation of monthly logarithmic prices, was higher in the five-year period between 2006 and 2010 than in earlier respective periods (Figure 3). The month-to-month variability of prices of all four crops was above 15 percent during this period.

Figure 3. Volatility of international prices for selected crops



Note: Price volatility is measured by the standard deviation of logarithmic monthly prices using World Bank international prices. The figures in each row refer to average values over the respective decade.

3. Theoretical and Analytical Developments

3.1 Theoretical Model

Supply response literature has seen several empirical and theoretical modifications, out of which two major frameworks have been developed. The first approach is a Nerlovian partial adjustment model, which allows us to analyze both the speed and the level of adjustment from actual output toward desired output. The second is the supply function approach that is derived from the profit-maximizing framework. This latter approach requires detailed input prices and simultaneous estimation of input demand and output supply equations. However, input markets, particularly land and labor markets, are either missing or imperfect in several developing countries. Moreover, this paper focuses on estimating acreage supply response. Thus, the econometric approach of the present study is in line with the partial adjustment framework enhanced with dynamic response, alternative price expectation assumptions, and the introduction of price risk variables.

There have been several applications of the Nerlovian model with certain modifications. These include the use of alternative expectation assumptions such as futures prices (Gardner, 1976), expected net returns rather than prices (Chavas & Holt, 1990; Davison & Crowder, 1991), and acreage value rather than prices or returns (Bridges & Tenkorang, 2009). Risk variables have also been included to capture farmers' behavioral characteristics (Liang et al., 2011). Furthermore, econometric developments have allowed more recent work to use panel data; time series data were often previously used to capture the dynamics of agriculture production.

The supply response function of a certain crop can be formulated in terms of its area, yield, or output. For instance, (desired) area of a certain crop in period *t* can be defined as a function of expected output prices and a number of other exogenous factors (Braulke, 1982):

$$A_t^d = \beta_1 + \beta_2 P_t^e + \beta_3 Z_t + \varepsilon_t \qquad (1)$$

where A_t^d is the desired area in period *t*, P_t^e is the expected price of the crop under consideration and of other competing crops, Z is a set of other exogenous variables including fixed and variable input prices, climate variables, and technological change, ε_t accounts for unobserved random factors affecting the area under cultivation with zero expected mean, and β_i are parameters to be estimated.

Since full adjustment of the desired area allocation may not be completed in the short run, the actual area adjustment is defined as a fraction δ of the desired adjustment:

$$A_t = \delta A_t^d + (1-\delta)A_{t-1} + v_t \qquad (2)$$

where A_t is the actual area planted at time t, δ is the acreage adjustment coefficient that ranges between 0 and 1, and v_t is a spherical error term.

Harvest-time prices are not realized at the time of planting. Thus, farmers form expectations about output prices based on their knowledge of past and present prices as well as other relevant observable variables. In the traditional Nerlovian model, such price expectation is modeled in an adaptive manner, in which farmers learn and adjust their expectations as a fraction of the deviation between their expected prices and the actual price in the previous period, *t–1*:

$$P_t^e = \gamma P_{t-1} + (1-\gamma)P_{t-1}^e + w_t \qquad (3)$$

where P_{t-1} is the output price at previous harvesting period, γ is the price expectation coefficient that ranges between 0 and 1, and w_t is a random error with zero expected mean.

Equations (1), (2), and (3) contain long-term equilibrium and expected variables that are not observable. However, after some algebraic manipulation, we obtain a reduced form equation containing only observable variables for estimation purpose:

$$A_t = \alpha_1 + \alpha_2 P_{t-1} + \alpha_3 A_{t-1} + \alpha_4 A_{t-2} + \alpha_5 Z_t + \alpha_6 Z_{t-1} + e_t \qquad (4)$$

Where $\alpha_1 = \beta_1\delta\gamma$, $\alpha_2 = \beta_2\delta\gamma$, $\alpha_3 = (1-\delta)(1-\gamma)$, $\alpha_4 = -(1-\delta)(1-\gamma)$, $\alpha_5 = \beta_3\delta$, $\alpha_6 = \beta_3\delta(1-\gamma)$ and $e_t = v_t - (1-\gamma)v_{t-1} + \delta\varepsilon_t - (1-\delta)\varepsilon_{t-1} + \beta_2\delta w_t$

The reduced form is a distributed lag model with lagged dependent variables. The estimated coefficients for each explanatory variable of equation (4), given logarithmic transformation, provide short-run price elasticities. We can obtain long-run elasticities by dividing short-run elasticities by the acreage adjustment coefficients. The long-run elasticity is greater than the respective short-run elasticity if both price expectation and acreage adjustment are smaller than one. A close-to-unity adjustment coefficient implies fast adjustment of actual acreage to desired acreage. On the other hand, if the adjustment coefficient is close to zero, the adjustment takes place slowly.

3.2 Review of Recent Applications

There are several empirical applications of the above model with respect to the estimation of supply response to price movements in several countries. Askari & Cummings (1977) and Nerlove & Bessler (2001) provide thorough reviews of the literature in this regard. This section presents a brief review of a few other recent applications of the Nerlovian framework and its variants in several different parts of the world.

Using panel data for the period 1970-1971 to 2004-2005 across various states in India, Mythili (2008) estimates short- and long-run supply elasticities for a set of crops. The results show that Indian farmers respond to price incentives in the form of both acreage expansion and yield improvement. This study indicates a slow acreage adjustment to desired levels in India. Another study by Kanwar and Sadoulet (2008) applies a variant of the Nerlovian model to estimate the output response of cash crops using panel data for the period 1967-1968 to 1999-2000 across 14 states of India. These authors employ dynamic panel estimation techniques and find that the expected profit has a statistically significant positive impact on acreages of five out of seven cash crops. Yu et al. (2012) apply a similar framework to estimate crop acreage and yield responses for Henan province in China. Using data from 108 counties for the period 1998-2007, these authors report that acreage and yield both respond to output prices. Other empirical applications for Asian countries include supply response estimations by Yu & Fan (2011) for rice production in Cambodia, Mostofa et al. (2010) for vegetable production in Bangladesh, and Imai et al. (2011) for several agricultural commodities for a panel of ten Asian countries.

The Nerlovian framework has also been applied to study food supply responses in Latin American countries. De Menezes & Piketty (2012) analyze a national soybean supply response model using state-level data in Brazil for the period 1990-2004 and find an elastic supply response. Another Brazilian acreage response study by Hausman (2012) reports a strong response to crop prices for soybean acreage but a weak one for sugar cane. Furthermore, Richards et al. (2012) estimate soybean supply response equations for three Latin American countries using data from the mid-1990s. Their econometric results show a significant soybean acreage response to own output prices in all three countries, with the strongest response in Brazil, followed by Bolivia and Paraguay.

Studies in Africa show that agricultural output is similarly responsive to crop prices, albeit with smaller responses than in advanced economies. For instance, Vitale et al. (2009) use farm-level data for the period 1994-2007 in Southern Mali to estimate supply response of major staple crops. Their findings show significant acreage responses to own crop prices and, in most cases, also to cross-prices. Muchapondwa (2009) study aggregate agricultural supply response models for Zimbabwe for the period 1970-1999 and finds short-run price elasticity of supply consistent with theory; however, the long-run elasticity is only significant at 10 percent and is atypically smaller than the short-run value. Other supply response studies in Africa include Subervie (2008) for aggregate agricultural commodities for many developing countries, Leaver (2004) for tobacco supply in Zimbabwe, and Molua (2010) and Mkpado et al. (2012) for rice supply in Cameroon and in Nigeria, respectively.

There are several econometric studies of supply responses in advanced economies. For the US, for instance, Huang & Khanna (2010) model the supply response of specific agricultural commodities to prices, whereas Roberts & Schlenker (2010) estimate the aggregate supply response of food calories of selected commodities to output prices. Supply response models by Sanderson et al. (2012) for wheat and by Agbola & Evans (2012) for rice and cotton acreages are two examples of such studies for Australia. Slightly modified versions of the partial adjustment framework were also applied for econometric estimation of crop production and acreage response in Canada. These include studies by Coyle et al. (2008), which estimates acreage and yield response models of wheat, barley, and canola in Manitoba and by Weersink et al. (2010), which estimates acreage responses of corn, soybeans, and winter wheat in Ontario.

The abovementioned empirical studies investigate supply responses to prices at the micro-, national, or at most regional scale, but there is a lack of equivalent research at the global level. This paper fills this gap by estimating global crop supply responses to output prices and price risk using dynamic panel econometric methods.

4. Econometric Model and Data

4.1 Econometric Model

Given the above theoretical model and assuming there are K countries observed over T periods, the supply function for each of the four crops can be specified as:

$$A_{kt} = \pi A_{k,t-1} + \alpha p_{k,t} + \varphi vol(p)_{k,t} + \lambda_1 w_{k,t} + \mu_t + \eta_k + \boldsymbol{u_{kt}} \qquad (5)$$

where A denotes the area under cultivation of a crop (wheat, corn, soybeans, and rice); p denotes spot or futures prices that are used as proxies for farmers' expectations of own and competing crop prices at planting time; $vol(p)$ is the volatility measure for only own crop prices; w refers to prices of variable inputs (e.g. fertilizer); μ captures time dummies to account for some structural changes or national policy changes; η denotes country-fixed effects to control for all time-invariant heterogeneities across countries; and u denotes the idiosyncratic shock. This study combines 32 countries and/or regions with different agro-climatic features (geographical location, soil type, and weather risk) that do not change over time but that potentially affect acreage response. We therefore include country-fixed effects to avoid any estimation bias that stems from omission of relevant variables. All quantity, output, and input price variables (except for price volatilities, which are rates) are specified as logarithms in the econometric models. Hence, the estimated coefficients can be interpreted as short-run elasticities.

Applying ordinary least squares (OLS) estimation to a dynamic panel data regression model such as in equation (5) results in a dynamic panel bias because the lagged dependent variable is correlated with country fixed effects (Nickell, 1981). Current acreage is a function of fixed effects (η_k), and therefore lagged acreage is a function of these country fixed effects. This violates the strict exogeneity assumption and makes the OLS estimator biased and inconsistent. An intuitive solution is removing the fixed effects by transforming the data. However, under the within-group transformation, the lagged dependent variable remains correlated with the error term; therefore the fixed effects (FE) estimator is biased and inconsistent.

While the correlation between the lagged dependent variable and the error term is positive in the OLS regression, the estimated coefficient of the lagged dependent variable is biased downward in the FE estimator (Roodman, 2009a, 2009b).

The true parameter estimator for the coefficient on lagged dependent variable typically lies between the OLS and the FE estimates. Anderson and Hsiao (1982) suggest an instrumental variable (IV) method to estimate a first difference model. This technique eliminates the fixed effect terms by differencing instead of within transformation. Since the lagged dependent variable is correlated with the respective error term, this method uses the second lagged difference as an IV. Although this provides consistent estimates, Arellano and Bond (1991) have developed a more efficient estimator, called differenced GMM, to estimate a dynamic panel difference model using all suitably lagged endogenous and other exogenous variables as instruments in the GMM technique (Roodman, 2009a). Blundell and Bond (1998) further develop a strategy named system GMM to overcome the abovementioned dynamic panel bias. Instead of transforming the regressors to purge the fixed effects and using the levels as instruments, the system GMM technique transforms the instruments themselves and make them exogenous to the fixed effects (Roodman, 2009a). The estimator in the differenced GMM model can have poor finite sample properties (in terms of bias and precision) when applied for persistent series or random-walk type of variables (Roodman, 2009b). The system GMM estimator allows substantial efficiency gains over the differenced GMM estimator provided that initial conditions are not correlated with fixed effects (Blundell & Bond, 1998). Thus, this paper employs the system GMM method to estimate the dynamic supply models. Nevertheless, results from alternative methods including pooled OLS, FE, differenced GMM, and quantile regression are reported for the sake of robustness checks.

Several statistical tests are done to check the consistency of the preferred GMM estimator. First, the Arellano-Bond test is conducted to check for the existence of any serial correlation in residuals. The test results, reported in the next section, indicate that the null hypothesis of no second-order autocorrelation in residuals cannot be rejected for nearly all production, acreage, and yield models, indicating the consistency of the system GMM estimator. Second, the Hansen test results cannot reject the null hypothesis of instrument exogeneity. The validity of the Blundell-Bond assumption is also confirmed by the Diff-in-Hansen test of the two-step system GMM. The test statistics give p-values greater than 10 percent in all cases, suggesting that past changes are good instruments of current levels and that the system GMM estimators are more efficient than the differenced GMM. Furthermore, the standard error estimates for all specifications are robust in the presence of heteroskedasticity and autocorrelation within panels. The Windmeijer (2005) two-step error bias correction is incorporated. Following Roodman (2009a, 2009b), the instrument set is "collapsed" to limit instrument proliferation.

4.2 Data

The data used in this study cover the 1992-2010 period. The empirical model utilizes global and country-level data to estimate global acreage responses for the four crops. The data cover all countries with a global area share of above half a percent (31 countries) and all the other countries as a single entity, the ‘Rest-of-World.’ While data on planted acreage are obtained from national statistical sources[1], harvested acreage comes from the Food and Agricultural Organization of the United Nations (FAO). Area harvested serves as a proxy for planted area if data on the latter are not available. International spot market output prices, crude oil prices, and different types of fertilizer prices and price indices are obtained from the World Bank’s commodity price database. All commodity futures prices are from the Bloomberg database.

Farmers’ price expectations are modeled using relevant spot and futures world price information available during planting time. Since they contain more recent price information for farmers, either spot prices observed in the month immediately prior to planting or harvest period futures prices quoted in the months prior to planting starts are used. Using these two price series to formulate producers’ price expectations makes the supply response models adaptive as well as forward-looking. Because the planting pattern varies across countries and crops, both futures and spot prices of each crop are country-specific. For countries in the rest-of-world (ROW), annual average spot and generic futures prices are alternatively used. We also include competing crop prices to estimate cross-price elasticities. In order to reduce the problem of multi-collinearity in the data, we include a single index of all competing crop prices in each of the acreage models. For the specifications with futures prices, the index contains prices of only two competing crop prices (not that of rice).[2]

International spot price volatility is included to capture price risks. Price volatility is calculated as the standard deviation of price returns, i.e. the standard deviation of changes in logarithmic prices. This detrends the variable so that a stationary series is used in the empirical model. Finally, yet importantly, fertilizer price indices are used to proxy production costs. These indices are also crop- and country-specific based on the planting pattern of each crop in each country. The fertilizer price index in the month prior to the planting season is used.

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[1] Data sources can be made available upon request.

[2] We use the calorie contents of each crop as a weight to construct the competing crop price indices. For example, calorie weighted index of corn, soybeans, and rice spot prices is included as a cross-price index in the wheat acreage model (spot price specification), whereas an index of only corn and soybean futures prices is included in the wheat acreage model with futures prices specification.

5. Results and Discussions

This section presents our econometric results. Results from the differenced GMM and the quantile regression estimation techniques are also reported. The former serves as a robustness check for the system GMM results, whereas the quantile regression results enable us to understand whether acreage response to price changes varies depending on the size of the area allocated for each crop. Tables A2 and A3 (in the appendix) report results from OLS and FE estimators, underlining that the system GMM estimated coefficients on the lagged dependent variables (Table 2) lie between the values obtained from the OLS and FE estimations. Two lags of the dependent variable are included to assess the dynamic relationship of crop acreage allocations. Cultivation of some crops (for example, rice) requires longer-term investments, and thus including further lags may be important to capture such dynamics. Nevertheless, the second autoregressive terms are not statistically significant in our acreage models except for corn, indicating that the dynamic relationship may not be longer than one agricultural season.

Tables 2 to 4 present acreage response estimates for each crop. The models are estimated using pre-planting month spot prices and harvest period futures prices (except for rice) as a proxy for expected prices at planting time.[3] Because these periods differ from country to country, US planting and harvesting periods are used as reference periods. Futures prices are taken from contracts traded at the Chicago Board of Trades (CBOT). In the case of wheat, the expected prices are derived from the average July wheat futures traded from October to December, whereas the futures prices for corn and soybeans are the average December corn futures prices observed from March to May and the average November soybeans futures prices observed from April to June, respectively.

The following discussion relies on the results obtained from the system GMM specification that uses spot prices unless stated otherwise. In general, crop acreages exhibit positive (negative) and statistically significant responses to own crop (competing crop) prices, consistent with economic theory. The results indicate that higher output prices induce producers to allocate more land for the respective crop.

The results in Table 2 show that the acreage of all crops positively respond to rising own crop spot prices, with short-run elasticities of 0.14 for soybeans, 0.09 for wheat, 0.06 for corn, and 0.03 for rice. Crop acreage responses to own futures prices are slightly larger than the corresponding responses to spot prices. Conditional on other covariates, a 10 percent rise in expected own crop (futures) price induces an acreage expansion of about 1.9 percent for soybeans, 0.8 percent for corn, and 1.1 percent for wheat in the short run. While the cross-price index is negative in all the crop acreage models, it has a statistically significant effect only on corn and soybean global acreages. Relying on the spot-price acreage specifications, a 10 percent

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[3] Rice futures markets have relatively shorter time series data, and local prices are unlikely to be strongly correlated with futures prices in several countries.

increase in the cross price index induces farmers to shift about 1 percent of their land away from each of corn and soybean cultivation. Although the short-run acreage elasticities are generally small, large coefficients on the lagged dependent variables indicate that long-run elasticities are larger. This implies that global acreage responds to price incentives but is not on-par with price increases in the short run.

Table 2. System GMM estimates of global acreage response[4]

Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Lagged own area (1)	0.905***	0.873***	0.711***	0.707***	1.138***	1.234***	0.755***
	(0.069)	(0.055)	(0.113)	(0.157)	(0.094)	(0.061)	(0.176)
Lagged own area (2)	0.070	0.058	0.255**	0.272**	-0.151	-0.243***	-0.240
	(0.082)	(0.042)	(0.093)	(0.125)	(0.094)	(0.064)	(0.173)
Own crop price (spot)	0.088***		0.055*		0.137***		0.027**
	(0.024)		(0.033)		(0.028)		(0.011)
Own crop price (futures)		0.110**		0.082**		0.185**	
		(0.042)		(0.038)		(0.076)	
Cross price index (spot)		-0.017	-0.117***		-0.094***		-0.024
		(0.063)	(0.029)		(0.020)		(0.034)
Cross price index (futures)		0.017		-0.065*		-0.188**	
		(0.020)		(0.037)		(0.073)	
Own price volatility	-0.221	-0.478*	-0.305	-0.24	0.687**	0.721**	0.028
	(0.195)	(0.240)	(0.217)	(0.279)	(0.291)	(0.300)	(0.057)
Fertilizer price	0.011	-0.016	0.053***	0.025	-0.029*	-0.032*	0.013
	(0.023)	(0.016)	(0.018)	(0.022)	(0.015)	(0.017)	(0.021)
N	*486*	*393*	*562*	*393*	*545*	*496*	*578*
F-test of joint significance: p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Test for AR(1): p-value	*0.071*	*0.079*	*0.026*	*0.048*	*0.005*	*0.001*	*0.077*
Test for AR(2): p-value	*0.544*	*0.419*	*0.094*	*0.197*	*0.526*	*0.232*	*0.723*
Diff-in-Hansen test: p-value	*0.624*	*0.429*	*0.416*	*0.337*	*0.431*	*0.322*	*0.433*

Notes: Two-step standard errors, clustered by country and incorporating the Windmeijer (2005) correction, are in parenthesis. *, **, and *** represent the 10%, 5% and 1% levels of significance. Columns marked (1) and (2) report results for which we use spot and futures prices, respectively.

Unlike own crop price level effects on acreage response, own price volatility does not have uniform effect on acreage of these four crops. Although not all the estimated volatility coefficients are statistically significant, the directional effect is as expected *a priori* (negative), except in the case of soybean acreage. Own price volatility has adverse implications for global wheat acreage allocations, whereas the estimated coefficients on price volatility of soybean acreage response is statistically significant and positive. The

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[4] All acreage response models are weighted by the global crop acreage share of each country.

positive effect of price volatility on soybean acreage is consistent with previous national level studies that find either insignificant or positive effects of price variability on soybean acreage supply (e.g. de Menezes & Piketty, 2012). One explanation for this may be that the majority of world's soybean producers are large commercial holders who are likely to be well informed about price developments.

Table 3. Differenced GMM estimates of global acreage response[5]

Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Lagged own area (1)	0.613***	0.575***	0.594***	0.593***	1.020***	1.089***	0.740***
	(0.053)	(0.064)	(0.063)	(0.071)	(0.096)	(0.087)	(0.069)
Lagged own area (2)	-0.054	-0.055	0.275***	0.238**	-0.095	-0.144**	0.247
	(0.043)	(0.046)	(0.082)	(0.091)	(0.074)	(0.068)	(0.249)
Own crop price (spot)	0.042*		0.056**		0.057**		0.026**
	(0.026)		(0.024)		(0.029)		(0.013)
Own crop price (futures)		0.062**		0.052**		0.088*	
		(0.028)		(0.025)		(0.040)	
Cross price index (spot)	-0.017		-0.126***		-0.107***		0.003
	(0.051)		(0.035)		(0.015)		(0.025)
Cross price index (futures)		-0.006		-0.054***		-0.159**	
		(0.030)		(0.018)		(0.058)	
Own price volatility	-0.167	-0.482***	-0.187	-0.095	0.877***	0.707	0.028
	(0.179)	(0.166)	(0.197)	(0.150)	(0.281)	(0.416)	(0.057)
Fertilizer price	0.028	0.027	0.072***	0.050***	-0.007	-0.006	0.013
	(0.036)	(0.031)	(0.015)	(0.015)	(0.020)	(0.016)	(0.021)
N	482	390	558	390	542	482	573
F-test of joint significance: *p*-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Test for AR(1): *p*-value	0.053	0.078	0.017	0.027	0.006	0.002	0.060
Test for AR(2): *p*-value	0.649	0.718	0.042	0.100	0.605	0.170	0.755
Diff-in-Hansen test: *p*-value	0.614	0.540	0.504	0.298	0.380	0.361	0.253

Notes: All regressions are two-step System GMM. Two-step standard errors, clustered by country and incorporating the Windmeijer (2005) correction, are in parenthesis. *, **, and *** represent the 10%, 5% and 1% levels of significance. Columns marked (1) and (2) report results for which we use spot and futures prices, respectively.

The once lagged dependent variables are both statistically and economically relevant in acreage response models of all crops. The estimated coefficients indicate producers' inertia, which may reflect adjustment costs in crop rotation, crop-specific land (and other quasi-fixed and fixed inputs), technology, and soil quality requirements. The estimated coefficients on the lagged dependent variables are close to one, indicating that

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[5] All acreage response models are weighted by the global crop acreage share of each country.

agricultural supply is much more responsive to international output prices in the longer term than in the short term.

Table 4. Quantile regression estimates of global acreage response

Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Quantile (0.25)							
Lagged own area (1)	0.992***	0.973***	0.856***	0.818***	1.009***	1.001***	0.958***
	(0.064)	(0.044)	(0.107)	(0.114)	(0.038)	(0.039)	(0.119)
Lagged own area (2)	0.011	0.032	0.154	0.194*	0.005	0.016	0.05
	(0.064)	(0.045)	(0.107)	(0.114)	(0.039)	(0.039)	(0.118)
Own crop price (spot)	0.016		0.069*		0.062		0.0004
	(0.031)		(0.041)		(0.058)		(0.025)
Own crop price (futures)		0.064		0.075		0.029	
		(0.046)		(0.073)		(0.075)	
Cross price index (spot)	-0.034		-0.143**		-0.122*		(0.025)
	(0.046)		(0.058)		(0.062)		0.039
Cross price index (futures)	-0.023		-0.040**		-0.086*		
	(0.025)		(0.020)		(0.036)		
Own price volatility	-0.085	-0.355	0.038	-0.015	0.181	0.158	-0.066
	(0.157)	(0.314)	(0.341)	(0.523)	(0.291)	(0.368)	(0.147)
Fertilizer price	0.024	0.008	0.04	-0.007	-0.001	0.018	0
	(0.017)	(0.029)	(0.027)	(0.024)	(0.021)	(0.039)	(0.017)
Intercept	-0.091	-0.339	0.103	-0.32	-0.011	-0.127	-0.348
	(0.239)	(0.220)	(0.262)	(0.273)	(0.199)	(0.313)	(0.222)
Pseudo R-square	*0.937*	*0.938*	*0.940*	*0.937*	*0.904*	*0.900*	*0.949*
Quantile (0.5)							
Lagged own area (1)	0.998***	0.970***	0.991***	0.939***	1.047***	1.035***	0.913***
	(0.049)	(0.057)	(0.073)	(0.105)	(0.065)	(0.055)	(0.096)
Lagged own area (2)	-0.003	0.023	0.01	0.064	-0.047	-0.034	0.084
	(0.049)	(0.057)	(0.074)	(0.105)	(0.066)	(0.056)	(0.095)
Own crop price (spot)	0.015		0.038*		0.075		0.022*
	(0.037)		(0.015)		(0.069)		(0.010)
Own crop price (futures)		0.112***		0.033		0.076	
		(0.039)		(0.036)		(0.085)	
Cross price index (spot)	-0.034		-0.111***		-0.087*		0.004
	(0.040)		(0.041)		(0.035)		(0.030)
Cross price index (futures)		-0.016		-0.038		-0.109	
		(0.022)		(0.032)		(0.091)	
Own price volatility	-0.175	-0.517**	0.239	0.24	0.172	0.135	-0.005

Table 4. Quantile regression estimates of global acreage response (Con't)

Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
				Quantile (0.25)			
Fertilizer price	0.03	-0.011	0.029	0.000	-0.01	-0.004	-0.002
	(0.022)	(0.014)	(0.019)	(0.017)	(0.015)	(0.022)	(0.012)
Intercept	0.084	-0.261**	0.28	-0.001	0.071	0.132	-0.094
	(0.234)	(0.129)	(0.176)	(0.136)	(0.156)	(0.200)	(0.120)
Pseudo R-square	*0.942*	*0.941*	*0.934*	*0.932*	*0.911*	*0.9053*	*0.956*
				Quantile (0.75)			
Lagged own area (1)	0.958***	0.947***	0.964***	0.970***	0.994***	0.966***	0.780***
	(0.071)	(0.118)	(0.080)	(0.112)	(0.088)	(0.064)	(0.090)
Lagged own area (2)	0.025	0.037	0.02	0.017	-0.014	0.014	0.207**
	(0.070)	(0.117)	(0.080)	(0.112)	(0.087)	(0.061)	(0.089)
Own crop price (spot)	0.078**		0.013		0.113		0.037*
	(0.031)		(0.041)		(0.095)		(0.020)
Own crop price (futures)		0.100***		-0.014		0.088	
		(0.028)		(0.050)		(0.144)	
Cross price index (spot)	-0.087		-0.165***		-0.115**		0.009
	(0.055)		(0.059)		(0.054)		(0.057)
Cross price index (futures)		-0.064		-0.063		-0.173*	
		(0.042)		(0.043)		(0.104)	
Own price volatility	-0.414	-0.486	0.178	0.569	0.617	0.638	0.003
	(0.341)	(0.297)	(0.394)	(0.442)	(0.445)	(0.512)	(0.048)
Fertilizer price	0.046*	-0.005	0.057**	0.006	0.010	0.04	-0.002
	(0.027)	(0.022)	(0.025)	(0.023)	(0.027)	(0.028)	(0.017)
Intercept	0.225	0.21	0.894***	0.569***	0.223	0.507	-0.013
	(0.315)	(0.221)	(0.239)	(0.215)	(0.322)	(0.474)	(0.207)
Pseudo R-square	*0.926*	*0.922*	*0.915*	*0.910*	*0.904*	*0.894*	*0.950*
N	*486*	*393*	*562*	*393*	*545*	*496*	*578*

Notes: Bootstrapped standard errors in parenthesis; *, **, and *** represent the 10 percent, 5 percent, and 1 percent levels of significance. Columns marked (1) and (2) report results for which we use spot and futures prices, respectively.

The quantile regression results in Table 4 provide some interesting information. First, the estimated once-lagged area elasticity is statistically significant and stable across quantiles, with a slightly declining trend when we move to higher quantiles. The second order autoregressive term is not statistically significant; this does not change across quantiles. The one season dynamic relationship in the acreage response of the four crops therefore appears to hold regardless of the size of the area cultivated for each crop. Second, own price elasticities are variable in terms of both sign and statistical significance across quantiles. More specifically, global acreage becomes more responsive to prices, both to own and competing crop prices, when the level of acreage increases. For example, global wheat statistically and significantly responds to own prices at the 75th percentile but not at the 25th percentile distribution of its acreage. The effect of the cross-price index is statistically significant for acreages of both corn and soybean across all quantiles. Fourth, the acreage impact of price volatility is statistically insignificant, and these conclusion remains the same across quantiles.

6. Conclusions

Using cross-country panel data for 1992-2010, this study investigates the global acreage impacts of world-level output prices and associated price variability. Estimation of the worldwide aggregate acreage response to input and output prices is essential for predicting the effects of possible developments in output and input prices on the global food supply. An adjustment in crop acreage allocation is a key short-run mechanism that agricultural producers can make to respond to price changes. Although the short-run price elasticities of global acreage are generally small, the response is much larger in the long run. Rising prices can therefore induce larger acreage (and hence production) expansion in the long term.

This study helps to answer why the current high global food prices have not brought about an increase in global agricultural supply, as might have been expected. The estimated short-run supply elasticities are generally small. Agricultural supply does not, in the short term, increase on-par with output price increases. In other words, agricultural producers need a longer time in order to make necessary production adjustments and investments to increase supply; agricultural supply is more elastic in the longer term. These results have policy implications for food supplies on the global scale as well as at national levels. The global food supply responds positively to higher prices, implying that the recent food price increases bring about production increases, and hence better food security. Moreover, the results have policy implications for enhancing smallholder farmers' market integration so that they are able to benefit from higher prices. It will also be worthwhile to eliminate policies that constrain transmission of international prices to local farm gate markets.

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Appendix A

Table A1. Countries and Regions

Region	Country
Africa	Egypt, Ethiopia, Nigeria, South Africa
Asia	Bangladesh, Cambodia, China, India, Indonesia, Japan, Kazakhstan, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand, Uzbekistan
South America	Argentina, Brazil, Mexico, Paraguay, Uruguay
Middle East	Iran, Turkey
North America	Canada, United States
Europe	European Union (EU), Russian Federation, Ukraine
Australia	Australia
Other	Rest-of-World (ROW)

Notes: Acreage is pooled across the 27 member countries for the EU (as of 2010) and across all the remaining countries for the ROW group.

Table A2. Fixed effects regression estimates of global acreage response

Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Lagged own area (1)	0.739***	0.728***	0.873***	0.861***	0.826***	0.832***	0.848***
	(0.095)	(0.105)	(0.047)	(0.058)	(0.062)	(0.064)	(0.070)
Lagged own area (2)	-0.054	-0.064	0.043	0.038	0.092	0.087	-0.168*
	(0.062)	(0.068)	(0.054)	(0.056)	(0.054)	(0.059)	(0.089)
Own crop price (spot)	0.02		0.022		0.112		0.049
	(0.043)		(0.036)		(0.192)		(0.048)
Own crop price (futures)		0.094*		0.007		0.078	
		(0.054)		(0.057)		(0.226)	
Cross price index (spot)	-0.064		-0.325***		-0.269**		-0.160**
	(0.050)		(0.111)		(0.123)		(0.076)
Cross price index (futures)		-0.002		-0.083*		-0.285	
		(0.026)		(0.046)		(0.217)	
Own price volatility	-0.180	-0.445**	0.407	0.864	0.014	-0.117	-0.272
	(0.175)	(0.208)	(0.422)	(0.624)	(0.545)	(0.558)	(0.300)
Fertilizer price	0.053	0.016	0.117***	0.029	0.076	0.138***	-0.04
	(0.032)	(0.030)	(0.036)	(0.042)	(0.049)	(0.048)	(0.041)
Intercept	4.682***	4.496***	2.326***	1.699***	1.371**	1.302***	3.369***
	(1.216)	(1.279)	(0.452)	(0.247)	(0.530)	(0.288)	(0.376)
N	*486*	*393*	*562*	*393*	*545*	*496*	*578*
R-squared: Within	*0.525*	*0.514*	*0.762*	*0.717*	*0.781*	*0.780*	*0.549*
F-test of joint significance: p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

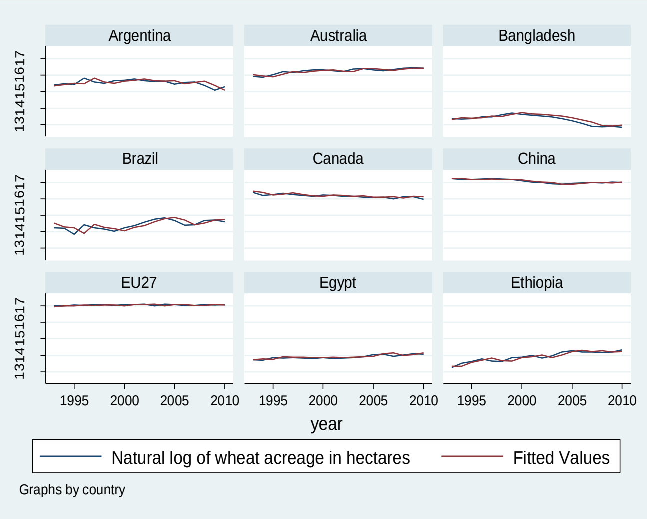
Note: Robust standard errors in parenthesis; *, **, and *** represent the 10 percent, 5 percent, and 1 percent levels of significance. Columns marked (1) and (2) report results for which we use spot and futures prices, respectively.

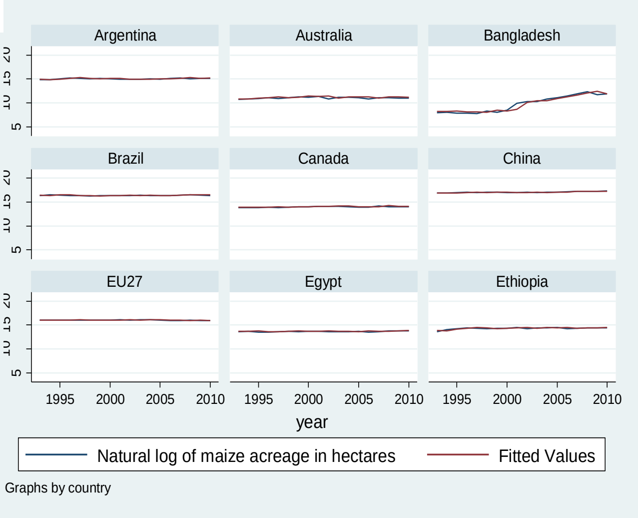
Table A3. Pooled OLS regression estimates of global acreage response

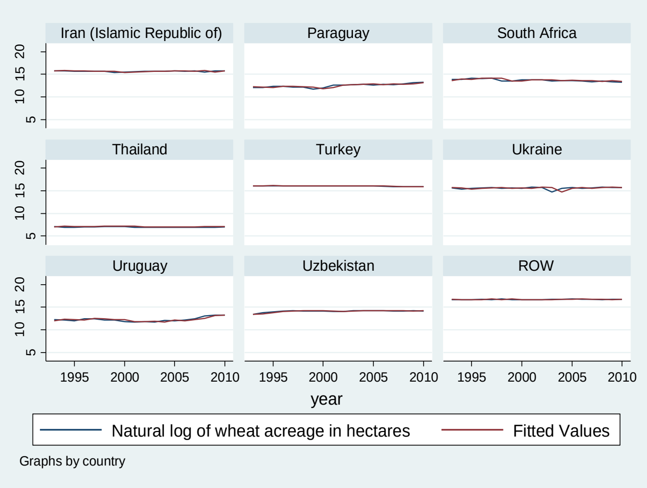
Variable	Wheat		Corn		Soybeans		Rice
	(1)	(2)	(1)	(2)	(1)	(2)	(1)
Lagged own area (1)	0.939***	0.935***	0.914***	0.899***	0.906***	0.905***	1.013***
	(0.075)	(0.082)	(0.059)	(0.074)	(0.077)	(0.081)	(0.226)
Lagged own area (2)	0.053	0.057	0.062	0.076	0.094	0.096	-0.016
	(0.075)	(0.081)	(0.047)	(0.058)	(0.077)	(0.081)	(0.225)
Own crop price (spot)	0.048**		0.031		0.082		0.040
	(0.018)		(0.050)		(0.141)		(0.042)
Own crop price (futures)		0.108*		0.029		0.061	
		(0.058)		(0.083)		(0.174)	
Cross price index (spot)	-0.08		-0.320***		-0.237**		-0.174*
	(0.052)		(0.109)		(0.118)		(0.096)
Cross price index (futures)		-0.005		-0.073		-0.28	
		(0.023)		(0.055)		(0.184)	
Own price volatility	-0.274	-0.573**	0.34	0.912	0.153	0.014	-0.275
	(0.239)	(0.291)	(0.498)	(0.786)	(0.747)	(0.776)	(0.296)
Fertilizer price	0.043	-0.004	0.089**	0.002	0.056	0.120**	-0.03
	(0.028)	(0.031)	(0.037)	(0.039)	(0.037)	(0.050)	(0.037)
Intercept	0.136	-0.337	1.570**	0.813	0.47	0.462	-0.970**
	(0.304)	(0.212)	(0.634)	(0.742)	(0.469)	(0.433)	(0.382)
R-squared	*0.993*	*0.992*	*0.978*	*0.972*	*0.985*	*0.983*	*0.993*
N	*486*	*393*	*562*	*393*	*545*	*496*	*578*

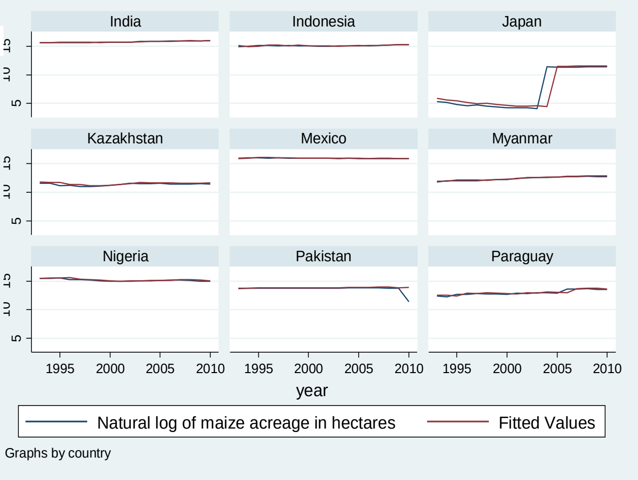
Note: Robust standard errors in parenthesis; *, **, and *** represent the 10 percent, 5 percent, and 1 percent levels of significance. Columns marked (1) and (2) report results for which we use spot and futures prices, respectively.

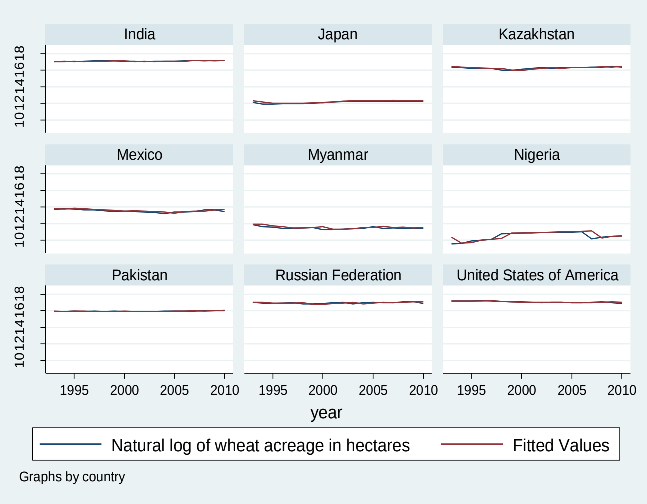
Appendix B: Fitted values compared to observed data based on the system GMM results

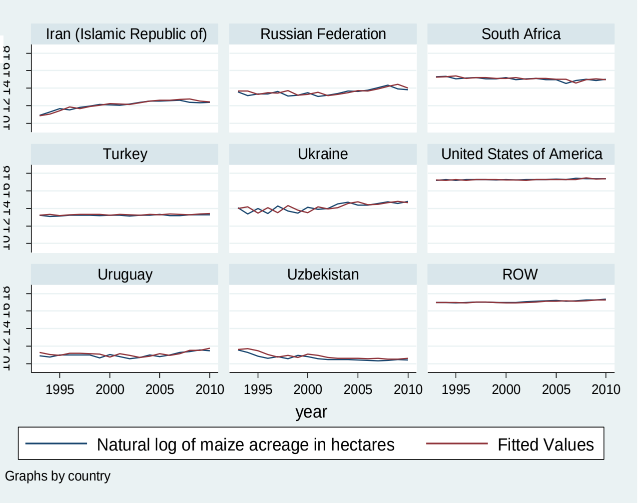


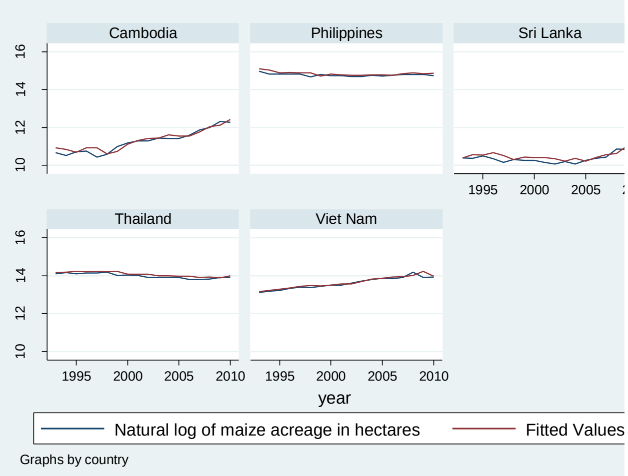








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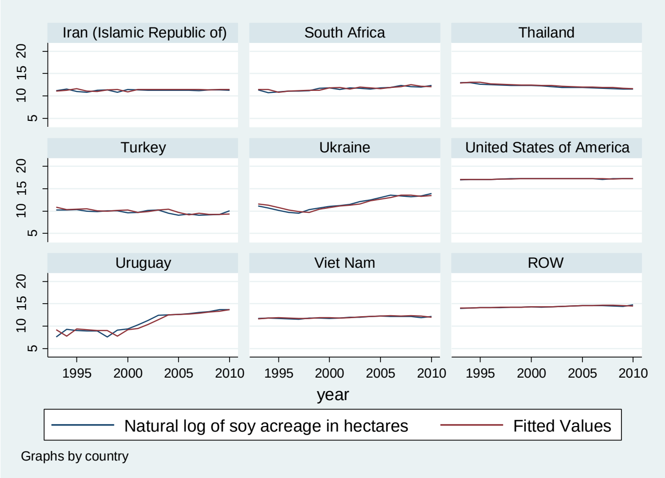
Philippines
Sri Lanka
Thailand
Viet Nam
10
12
14
16
1995
2000
2005
2010
year
Natural log of maize acreage in hectares
Fitted Values
Graphs by country


Iran (Islamic Republic of)
South Africa
Thailand
Turkey
Ukraine
United States of America
Uruguay
Viet Nam
ROW
5
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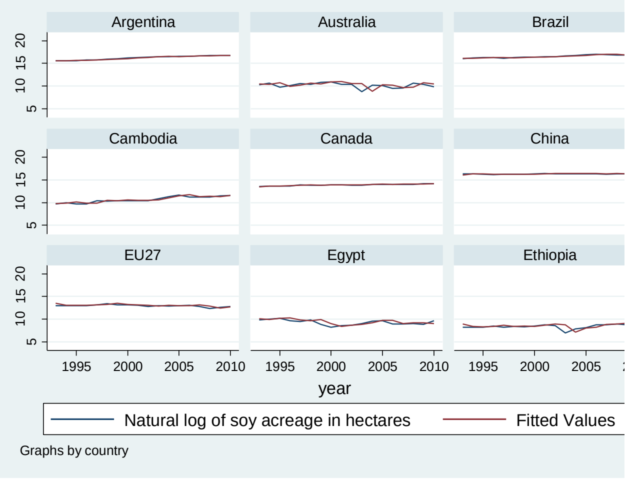
20
1995
2000
2005
2010
year
Natural log of soy acreage in hectares
Fitted Values
Graphs by country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EU27
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Ethiopia
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1995
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2005
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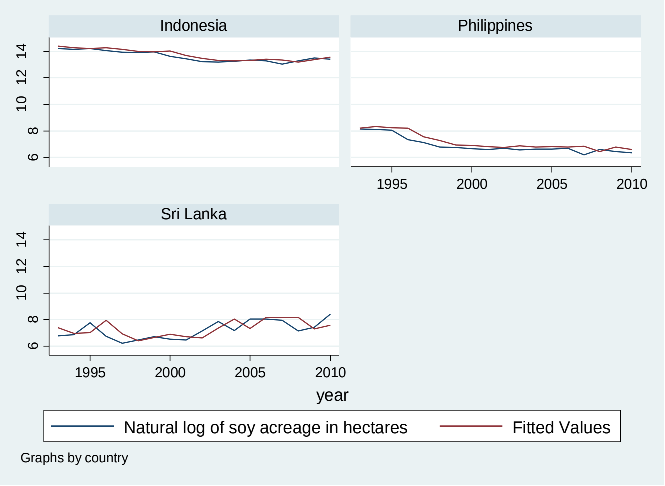
year
Natural log of soy acreage in hectares
Fitted Values
Graphs by country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Philippines
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1995
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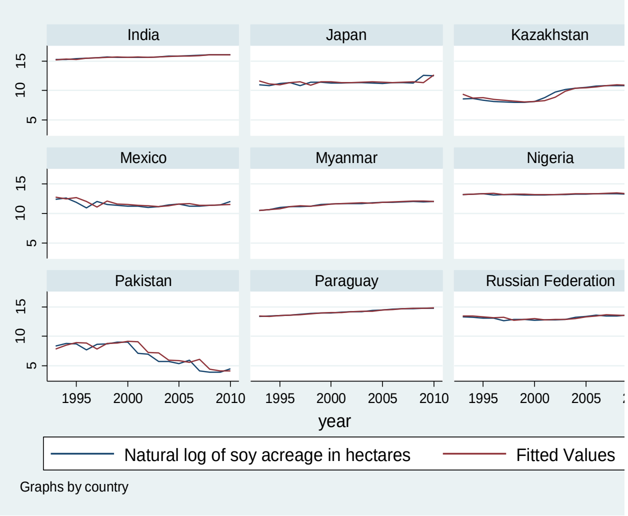
year
Natural log of soy acreage in hectares
Fitted Values
Graphs by country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Japan
Kazakhstan
Mexico
Myanmar
Nigeria
Pakistan
Paraguay
Russian Federation
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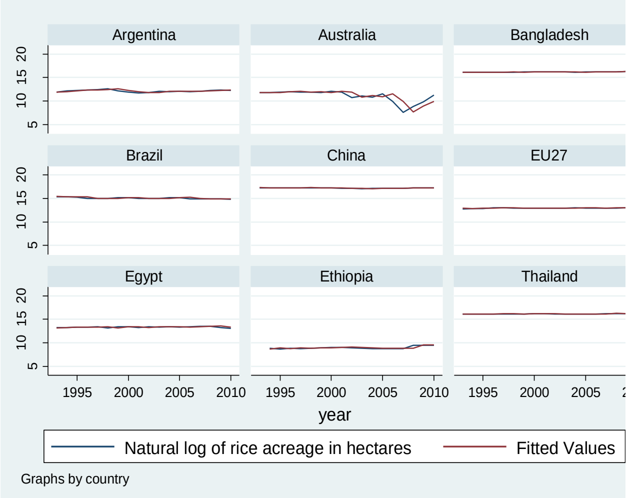
Natural log of soy acreage in hectares
Fitted Values
Graphs by country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Ethiopia
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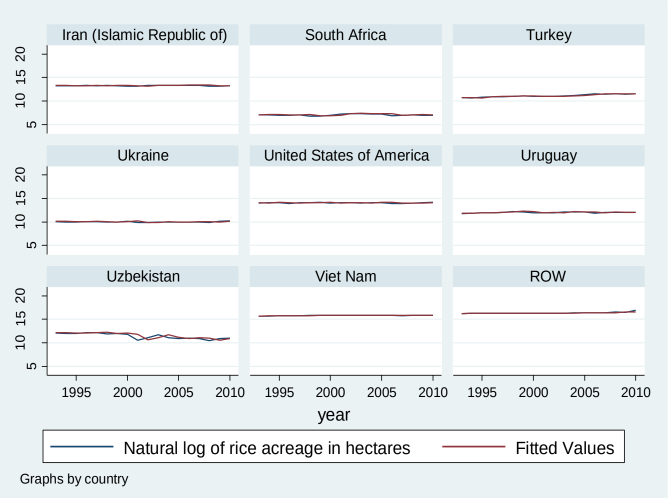
year
Natural log of rice acreage in hectares
Fitted Values
Graphs by country


Iran (Islamic Republic of)
South Africa
Turkey
Ukraine
United States of America
Uruguay
Uzbekistan
Viet Nam
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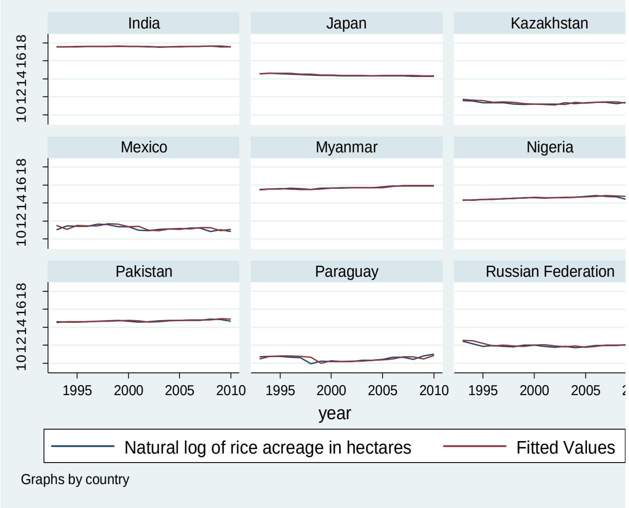
2010
year
Natural log of rice acreage in hectares
Fitted Values
Graphs by country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Japan
Kazakhstan
Mexico
Myanmar
Nigeria
Pakistan
Paraguay
Russian Federation
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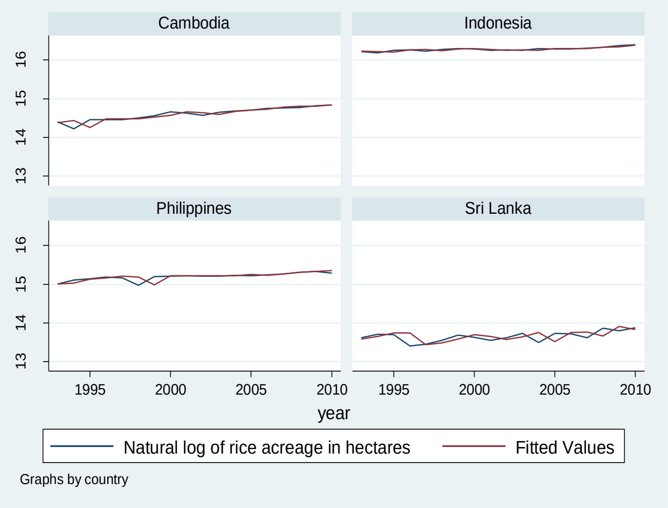
year
Natural log of rice acreage in hectares
Fitted Values
Graphs by country


Cambodia
Indonesia
Philippines
Sri Lanka
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1995
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year
Natural log of rice acreage in hectares
Fitted Values
Graphs by country

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