Assessing Global CGE Model Validity Using Agricultural Price Volatility

By

Valenzuela, Ernesto

Hertel, Thomas

Keeney, Roman

Reimer, Jeff

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Ernesto Valenzuela, Thomas W. Hertel, Roman Keeney, and Jeffrey J. Reimer

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Corresponding author address: evalenzuela1@worldbank.org.

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Abstract
Computable General Equilibrium (CGE) models are commonly used for global agricultural market analysis. Concerns are sometimes raised however, about the quality of their output since key parameters may not be econometrically estimated and little emphasis is generally given to model assessment. This article addresses the latter issue by developing an approach to validating CGE models based on the ability to reproduce observed price volatility in agricultural markets. We show how patterns in the deviations between model predictions and validation criteria can be used to identify the weak points of a model and guide development of improved specifications with firmer empirical foundations.

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Despite their widespread use in policy analysis, computable general equilibrium (CGE) models are sometimes criticized for having uncertain empirical foundations and for being insufficiently validated (Jorgenson 1984; Kehoe, Polo, and Sancho 1995). The problem of endowing large CGE models with numerical parameters values is formidable, and numerous choices also have to be made about model structure. In many cases the trustworthiness of a model may be based largely on the assertions of the modeler. As CGE models become more widely used, it is essential to have a formal means of assessing their empirical validity.

This article presents a methodology for validating CGE models on a sector-by-sector basis. The approach developed here can help one gauge the accuracy of a model's results, it can enable comparison to competing CGE models, and – most importantly – it can inform the development of improved specifications. Emphasis is placed on techniques for validating and improving models as opposed to arguing for a particular CGE model.

The validation approach is inspired by the work of Kydland and Prescott's widely received dynamic competitive-equilibrium growth modeling work. In their 1982 article, they develop a methodology for model calibration that involves mapping out a model's responses for historical technological shocks and then comparing them to the variance of national output. Hertel, Reimer, and Valenzuela (2005) show how this can help in the calibration of a commodity stockholding model for a static, short-run global CGE framework.

Our approach also relates to earlier work by Tyers and Anderson (1992) and Vanzetti (1998), who model uncertainty in world food markets by sampling from a distribution of random supply shocks. Like them, we focus on agricultural commodities since their weather-induced supply variation translates into a series of natural historical experiments. We incorporate this variation into a CGE model as technology shocks at the individual sector level. The model can then be validated against the observed variance of national commodity prices.

Validating the model against agricultural commodity price changes also coincides with the current focus of many global CGE modeling efforts. A key question is the potential impact of rich-country agricultural support and protection policies on incomes and poverty in developing countries. Agricultural policy impacts are transmitted to developing countries through world markets – specifically, through commodity price changes. It follows that a model's ability to replicate observed price changes should be of central concern to validation efforts. In order to permit maximum clarity in our investigations, we focus on a single commodity – wheat.

The CGE model that we seek to validate is the GTAP (Global Trade Analysis Project) model (Hertel 1997). This model is widely used by international agencies and governments to evaluate trade policy scenarios, and thus is a good candidate for validation. In comparing actual versus simulated price variation, we find that this model performs quite well for some countries. However, our most interesting findings relate to the pattern by which the model *fails* to replicate observed behavior in other markets. It tends to overstate price volatility in the major net importing markets, while understating price volatility in major exporting regions.

This is a striking result that arises from the tendency for countries to insulate domestic markets from world prices. The standard GTAP model assumes perfect price

transmission and thus overlooks the ensemble of policies and institutions that often serve to stabilize domestic markets and destabilize world markets. Examples include policies such as variable import levies and institutions such as state-trading enterprises and commodity agreements.

To account for the incomplete transmission of world prices, we modify the standard GTAP model to introduce active market insulation by importers. In particular, we estimate and incorporate price transmission elasticities into the model (Bredahl, Meyers, and Collins 1979). Once this modification is undertaken, the model is again evaluated relative to the same metric – predicted versus observed price volatility. The richer formulation improves model performance but also suggests a truly satisfactory reconciliation of observed and predicted outcomes can only come through explicit modeling of the key policies in individual markets. The validation method developed here provides a meaningful way of documenting how such modifications would improve model performance.

The remainder of the article is organized as follows. The next section reviews the practice of model validation and its application to large scale CGE models. The third section describes the main characteristics of the model being tested, and outlines the methodology employed in the validation exercise, namely the use of stochastic simulations focusing on annual variability in supply. The following section presents the results, which center on a comparison of predicted and observed price volatility. Finally, the article introduces a simple approach to incorporating incomplete price transmission between border and domestic prices, as implied by historical evidence.

Background on Model Validation
Gass (1983) provides the starting point for discussion of the validation of simulation models. He stresses the need for credibility in policy related simulations, but suggests that such models can never be truly validated. However, by subjecting a simulation model to *invalidation* tests we can become more confident that the model is not invalid, thereby improving its credibility.

Gass argues that the central concern of policy models should be *replicative validity*, as opposed, for example, to a singular focus on a model's underlying theoretical assumptions. Replicative validity essentially means that a model's simulated outcomes match historical outcomes over some appropriately chosen period of time. This process facilitates: (a) understanding of the model by potential users, (b) exposition of the strengths and weaknesses, (c) an assessment of the model's limitations in a predictive capacity, and (d) information on the proper level of confidence to attach to results. McCarl (1984) adds that validation can point the way for adaptations that produce better predictions in an area where a model was previously limited.

While the operations research literature continues to devote considerable attention to the validation of simulation models (reviewed in Kleijnen 1999), there are few cases of CGE models being tested against the historical record. Kehoe, Polo, and Sancho (1995) offer one exception. They validate a CGE model of the Spanish economy in terms of its predictions of the impacts of tax reform, by attempting to control their single-region CGE model for behavior it could not be expected to reproduce (e.g., the impact of a drought in the base year). Their experiment deals with shocks to a single, *national* economy, making

the process of isolating events, and exogenously introducing their impacts into the model, considerably more straightforward than for a *global* model.

We rarely have the kind of natural experiment that is needed to validate a large scale partial, or general equilibrium global model. For instance, in the case of multilateral trade liberalization, the policy changes are usually very modest, and are phased in over a long period of time – particularly when compared to the other short-term factors perturbing the world economy, such as wars, currency crises, and trade embargoes.

Gehlhar (1997) encounters such difficulties when validating a global trade model using policy shocks. He uses a backcasting simulation to evaluate the validity of GTAP model results versus observed outcomes concerning East Asian economic growth in the 1980s. He finds that the model performs adequately with respect to the direction of change in trade shares, but is otherwise weak in terms of predictive power. He then alters the model, separating labor inputs into skilled and unskilled components, and increases the trade elasticities by 20% from their base values. These alterations significantly improve the validation results in the particular case of East Asian growth.

Fox (2004) follows Kehoe, Polo, and Sancho's lead in developing summary goodness-of-fit measures to assess the North American Free Trade Agreement predictions of Brown, Deardorff, and Stern (1992), using the Michigan Model of Production and Trade. In implementing shocks to capital and labor endowments and allowing for international capital mobility, he finds that the model does a good job in capturing the qualitative pattern of trade changes. However, it fails to simulate the large magnitude of trade changes in certain sectors. He suggests this may be due to the low magnitude of the elasticities used in the model, and the Constant Elasticity of Substitution representation of trade.

Liu, Arndt, and Hertel (2004) formalize the approach of Gehlhar (1997) by developing an approximate likelihood function to assess the quality of model performance over the (backcasting) period of 1986-1992. They use this framework to test the widely maintained hypothesis known as the "rule of two," whereby the import/import substitution elasticities are twice as large as the import/domestic elasticities for comparable goods.

Our work is also inspired by the real business cycle (RBC) literature, which aims to develop models that are capable of mimicking correlations and volatility among consumption, output, investment, and labor in time-series data. Kydland and Prescott (1982) develop a dynamic stochastic RBC model in which agents make decisions conditional on prior decisions and the realizations of random variables. Calibration involves mapping out the model's responses for different sets of parameters and comparing them to stylized facts over the same time period. Parameters are selected so that steady state distributions of simulated outcomes match those of actual outcomes when Hicks-neutral stochastic shocks are made to aggregate production. Kydland and Prescott use autocorrelations and correlations to compare predicted and observed historical values. This work has inspired a vast literature that addresses questions related to those dealt with in this article, including a strand on the international dimension of real business cycles (e.g., Backus, Kehoe, and Kydland, 1992).

Our validation exercise draws insights from this literature, with some important differences. For example, while agents in our CGE model are subjected to stochastic shocks they operate within a static, deterministic environment. They have no

expectations about the future and do not avail forward contracts or hedging, for example. In turn, the CGE model is a global model with much greater detail in terms of sectors, productive factors, consumption and trade than the models used in the RBC literature. We implement sector-specific technology shocks and focus on the model's ability to reproduce historical price variation for a particular market.

Methodology

The validation experiment employs the method of stochastic simulation, using shocks derived from a time-series model of wheat production to measure the randomness inherent in annual output. The residuals are used to create a distribution reflecting random productivity variation for wheat, by producing region. These productivity shocks generate endogenous fluctuations in production that match those in the data. Solving the CGE model repeatedly while sampling from this distribution yields a distribution of corresponding market price changes for wheat, by region. Standard deviations based on these model outcomes are then compared to observed outcomes for year-to-year price changes in order to validate (or invalidate) the model.[1]

With this overview, the following sub-sections describe: (a) the data aggregation and main characteristics of the GTAP model, (b) the method of measuring production variability to use as an input to the model, (c) the stochastic simulation method employed in the CGE model, and (d) the calculation of actual price volatility for comparison with model results.

GTAP Model of Global Trade and Database

The GTAP global CGE model is a good candidate for validation as it is widely used by international agencies and governments to evaluate trade policy scenarios (Hertel 1997). The model employs the simplistic but robust assumptions of perfect competition and constant returns to scale in production activities. This is appropriate given the focus on bulk commodity production in this article.

The GTAP model includes: demand for goods for final consumption, intermediate use, and government consumption; demands for factor inputs; supplies of factors and goods; and international trade in goods and services. Bilateral international trade flows are handled using the Armington assumption, whereby products are exogenously differentiated by origin. Once again, this assumption seems quite appropriate for the case of wheat, as the agro-ecological characteristics of individual countries tend to dictate the type of wheat that is grown. The all-important, Armington elasticities of substitution in trade in this version of the model have been econometrically estimated using bilateral data on imports, tariffs and international transport costs (Hertel et al., 2003).

The GTAP 5.4 database is used in this analysis. It features 1997 as the benchmark year (Dimaranan and McDougall 2002). This large database is aggregated to depict 17 regions and 24 sectors, with a primary focus on large wheat trading regions and on retaining sufficient detail in the agri-food sectors (Appendix tables A1 and A2).

Determining Commodity Supply Variability

The first step in validating the model is to develop the set of shocks that will be used in the stochastic simulations of the CGE model. The shocks should correspond to sources of

volatility that are exogenous to the model. We therefore need to characterize volatility in the international wheat market.

Vanzetti (1998) examines the international wheat market between 1960 and 1994 and observes that price volatility is largely a supply-side phenomenon. He finds that by removing the systematic changes in output, one is left with prediction errors that represent output fluctuations attributable primarily to weather. Our analysis of international wheat production data from 1966 to 2002 supports this general finding (FAOSTAT 2004).

To characterize the systematic component of wheat output, we elect to fit a time-series model to FAO data on annual wheat production for each region. In thinking about the particular specification to use, we make two observations. First, past values of output appear to carry a great deal of information about current values. Second, current prediction errors arise largely from weather shocks to production. Based on these observations, an Autoregressive Moving Average (ARMA) process is selected to fit to the production data. This has become popular for its forecasting properties relative to structural econometric specifications. It relies on past values of the endogenous variable as well as past prediction errors to arrive at a current forecast (Kennedy 1997, p. 248). The specification takes the form:

(1) $$Y_t = \sum_{i=t-p}^{t-1} \phi_i Y_i + \sum_{j=t-q}^{t} \theta_j \varepsilon_j \ ,$$

where t is the time period, ϕ and θ are parameters to be estimated, Y is wheat output, and ε is the prediction error in a given time period. Key aspects of equation (1) entail specification of the number of autoregressive terms (p) and number of moving average terms (q). We adopt the Box and Jenkins approach of evaluating autocorrelations and partial autocorrelations to determine appropriate lags p and q, and opt for parsimony as a guiding rule. Parameter estimates for each region are shown in table 1.

The fit of this model in the case of Japan is shown in figure 1. Assuming a stochastic trend, this graphs shows that the fitted model is effective in tracking the variation of wheat production in Japan, which appears to be on a decade-long cycle.

The key result of interest from the regressions is the normalized standard deviation of the estimated residuals, reported in column 1 of table 2. This is calculated as $\sqrt{V}$ divided by the production mean and multiplied by 100, where V is the variance of the estimated residuals. It summarizes variability of the non-systematic aspect of production in each region from 1966 to 2002.

The greatest variations in production, after eliminating the trend, are found in Brazil, Australia, and Argentina, with variations amounting to one-fourth (or more) of the average annual volume of production (table 2, column 1). The least variation is found in net importer regions, including: South Asia, the European Union, China, and the Middle East North Africa region. They have less than a 10% random variation, relative to mean production. The rest of the regions are a mix of net importers and exporters and exhibit moderate variation of about 15%.

The next step is to translate wheat production variability into a form useful for stochastic simulation of the CGE model.

Stochastic Simulation

Following the approach of Arndt (1996) and Pearson and Arndt (2000), we use a symmetric triangular distribution as to approximate the distribution of residuals from our single region time series equations. The endpoints of the symmetric triangular distribution are recovered using the mean and variance of the estimated residuals according to the formula, $c = \mu \pm \sqrt{6V}$, where c is an endpoint of the distribution, μ is the mean of the residuals, and V is the variance of residuals. Table 2 reports the approximated triangular distribution for each region. This estimated distribution of productivity shocks for each region provides the basis for a policy-neutral stochastic simulation of the CGE model.

Our method of stochastic simulation requires solving the CGE model with respect to this approximating distribution of productivity shocks such that means and standard deviations can be recovered for the endogenous (GDP deflated) market prices. Formally following Arndt (1996), the general equilibrium model is defined in a general form by:

(2) $G(k,e) = 0$

where k is a vector of endogenous variables, and e is a vector of exogenous variables. A particular solution to equation (2) for a vector of exogenous variables can be expressed as a function of k on e, $k = r(e)$, thus defining a vector of results of interest $H(e) \equiv r(e)$. In our framework, e is the vector of productivity shocks, and in our policy-neutral simulation, the solution values for endogenous variables are attributable only to this productivity variation. Thus, the endogenous variable results are characterized by both mean (3) and variance (4) formulae as given below:

(3) $E[H(e)] = \int_{\Omega} H(e)g(e)de$

(4) $E\left[(H(e) - E[H(e)])^2\right] = \int_{\Omega} (H(e) - E[H(e)])^2 g(e)de$,

where $g(e)$ represents the multivariate density function of exogenous productivity shocks, and Ω is the region of integration.

Arndt's (1996) approach to evaluating (3) and (4) above is a numerical integration exercise using repeated solutions for the general equilibrium model and the approximating distribution of exogenous variables. As an alternative to Monte Carlo, Arndt (1996) demonstrates that the Gaussian Quadrature (GQ) numerical integration technique provides robust results with many fewer draws from the distribution of random variables (it was developed by Stroud (1957) and Haber (1970), and implemented to policy analysis by Devuyst (1993) and DeVuyst and Preckel (1997)). Pearson and Arndt (2000) implement the GQ drawing procedure in the GTAP framework using Stroud's (1957) formulae for equally weighted, order three quadratures given symmetric, independent distributions of a variable γ with mean zero and standard deviation one.

The Stroud quadrature requires two draws from the approximation of the multivariate distribution for each of n stochastic exogenous variable. Formally $\Gamma_l = (\gamma_{l1}, \gamma_{l1}, ..., \gamma_{ln})$ is the lth quadrature point (in n-space) with l going from 1 to $2n$. The s pairs of systematic draws from $\gamma \sim (0,1)$ are defined by Stroud's as in equation (5), where s goes

from 1 to $n/2$, until the maximum integer not exceeding $n/2$. Equation (6) converts the GQ draws on γ to the appropriate values for our simulation given the vector of means and (diagonal) covariance matrix of the productivity shocks, and defines the lth quadrature for which the model is solved.

$$(5) \qquad \gamma_{l,2s-1} = \sqrt{2}\cos\left(\frac{(2s-1)\,l\pi}{n}\right) \qquad\qquad \gamma_{l,2s} = \sqrt{2}\sin\left(\frac{(2s-1)\,l\pi}{n}\right)$$

$$(6) \qquad \Phi_l = \mu + \sqrt{V}\,\Gamma_l$$

Collecting all individual l^{th} solutions in the CGE model, and weighting them equally by $1/l$, we evaluate numerically the resulting moments of our endogenous variables with respect to variation in productivity consistent with equations (3) and (4).

Using this approach to stochastic simulation entails some cost in terms of additional assumptions, as we need to assume that all productivity shocks introduced to the model are independently and symmetrically distributed, and accuracy is dependent on the ability of a third order polynomial to approximate the GTAP endogenous variable solutions. On the first point, we assume independence across shocks in our estimation procedure for productivity shocks and are not able to reject normality of the residuals for these regressions. With regard to the second point, Arndt and Hertel (1997) find that order three quadratures perform quite well in their study of stochastic protection levels.

Determining Wheat Price Volatility
We now have an approach for developing predictions of wheat price volatility by region with the standard GTAP model. This section develops the criterion to which these predictions can be compared.

In choosing a time frame over which to calculate observed wheat price variability, several considerations are taken into account. We first note that we seek to test the model in the context of a policy-neutral experiment. This suggests that the time frame should not encompass a period of dramatic policy changes in the wheat markets. In addition, since the GTAP benchmark data refer to 1997, the policy environment of the time frame should not be overly dissimilar from those in place during this benchmark period. In this context, one potential problem is the emergence of the Uruguay Round multilateral trade liberalizations in the early 1990s. This should not play a big role, however, as the resulting liberalization for wheat was relatively modest and often involved "dirty tarrification" whereby liberalization was avoided via judicious choice of base period prices (Mitchell and Mielke 2005). In addition, cuts in domestic support for wheat production have not been large, as most countries focused on other sectors in meeting Uruguay Round commitments.

A more important issue is government stockholding of wheat by major exporters. Stockholding was a significant part of the international market before 1990, but is not modeled within the standard GTAP framework (on this, see Hertel, Reimer, and Valenzuela 2005).

With these considerations in mind we choose the 1990-2001 period to calculate the observed price volatility by region. There was relatively little government stockholding in

this period, and there are enough observations to get a reasonable representation of price volatility.

The observed measure of wheat price volatility is calculated using data from the Food and Agricultural Organization (FAOSTAT 2004). The GTAP model makes predictions of prices in real terms, using the global factor prices as numeraire. However, the FAO price series are nominal and have therefore been deflated by the gross domestic product (GDP) index from International Financial Statistics (IFS). Accordingly, we also adjust the GTAP price predictions by a GDP deflator as well, before undertaking our validation comparison. Another issue is that the model makes predictions in terms of percentage changes from base levels. This is taken into account when calculating the validation criterion, since our measure of price volatility is the *standard deviation of percentage price changes*.

The first and second columns of table 3 report the standard deviation of percentage changes in observed, annual wheat prices. The results associated with nominal prices are presented, but price volatility in real terms (column 2) is the validation criterion used in the remainder of the article. The wheat price volatility for a regional aggregate is given as a *range* as opposed to a composite calculation of country-specific wheat price volatilities.

Wheat price volatility in real terms for Australia, Canada, and the U.S., for example, is 21.4, 16.6, and 15.8 (table 3). These values are quite similar to the 15% wheat price variability recently reported by Gilbert (2003), who also uses FAO data, although his calculations correspond to levels as opposed to percentage price changes.

Results

Overview

The simulated price volatilities for the standard GTAP model are reported in the third column of table 3. We first compare these to the observed real price volatilities for the eight individual countries at the top of the table. The simulated outcomes for Canada, Australia and China are close to the observed outcomes. Likewise, Japan has the lowest actual volatility, and – although not a good match – is also predicted by the model to have one of the lowest volatilities of any region. The model performs notably less well for the other countries, with Brazil as the most striking outlier.

The results for the aggregated regions in the lower part of table 3 are similar in nature. The model's results are within, or extremely close to, the observed range of price volatility in three of the aggregate regions: Middle East and North Africa, Rest of Latin America, and Other Europe. The close performance for the EU is notable. There is little variation in the degree of price variation across countries within this grouping (5.9 - 7.8), and the model prediction (9.1) is close to the observed range. The EU could be a special case since their net export position is largely a device of policy (Mitchell and Mielke 2005).

The model slightly under-predicts price variation for the remaining aggregated region, Other Europe. In thinking about why this happens, consider Poland and Romania, for example. These two countries in Other Europe experienced dramatic agricultural policy regime shifts during this period. These policies induced an increase in price volatility, which in Poland's case was about 42%. Clearly these are changes that have not been taken into account in the model, and, to the extent they dominate the landscape in

Eastern and Central Europe, the model cannot be expected to perform well for this region.

Concerns are sometimes voiced that CGE models tend to uniformly under-predict volatility. By contrast, at other times it has been suggested that they uniformly *over-*predict volatility. The results in table 3 would seem to allay such concerns. There is no systematic under- or over-prediction of volatility, at least in this GTAP-wheat example. The results tend to be mixed.

Perhaps the most interesting aspect of the results is that, when the model fails, it does so in a systematic way. To see this, figure 2 plots the simulated price volatility against the observed price volatility for the eight cases where a specific volatility is observed (as opposed to a range). Two countries, China and Australia, are very close to the 45 degree line, and thus the model performs well in these cases. By contrast, observations below the 45 degree line signify under-prediction by the model, and observations above the 45 degree line signify over-prediction by the model.

The pattern of under- and over-predictions closely mirrors whether a country tends to be a net importer or net exporter of wheat. Japan, Brazil, and China are all net importers of wheat, and the model over-predicts price volatility in these same regions (though only slightly for China). By contrast, the U.S., Canada, and Argentina are all large net exporters of wheat, and all have values below the 45 degree line. Mexican wheat price volatility is likewise under-predicted, but this may have more to do with the fact that its market has become fairly closely integrated to that of the U.S. in the wake of NAFTA. Thus, with the exception of Australia, for which there is an acceptable match in the prediction, the net exporting regions tend to have more volatility than predicted by the model.

Characteristics of Key Importers
The pattern of over- and under-prediction provides a great deal of information regarding how the model can be improved. The model does not account for certain factors that result in lower price volatility in import markets and higher price volatility in export markets. This issue merits specific discussion, and we briefly examine some of the interventions in Brazil, Japan, and China over the time period in question.

In Brazil, the Government operates a minimum support price for wheat, and subsidizes domestic production through loan programs (Buainain and da Silveira 2002, Mitchell and Mielke 2005). In the middle of the historical period under consideration, restrictions were imposed on the minimum income support policy. Integration with the Argentinean wheat market under MERCOSUR also had an impact on the Brazilian wheat market during this period (Maluf 1999).

Japan's strong barriers against wheat imports have long insulated domestic producers from foreign competition (Dyck 2004). Prior to the implementation of the income stabilization fund in 1999, the Food Agency of the Ministry of Agriculture, Forestry, and Fisheries (MAFF) acted as a single desk buyer for wheat (Fukuda, Dyck, and Stout 2004). Japan's Government currently controls wheat trade with a tariff-rate quota, imposing a prohibitively high tariff on imports outside the quota. It also provides domestic support in the form of diversion from rice programs under the Production Adjustment Promotion Plan (PAPP), as well as crop insurance. In order to efficiently

buffer international price variation, Japan also maintains stocks of wheat for national security purposes, amounting to about 2-3 months of consumption (FAOSTAT 2004).

In China's case, wheat is the main imported agricultural commodity. During the 1990-2000 period, China undertook major reforms in the wheat market, lowering support prices to near world market levels (Mitchell and Mielke 2005). For most of this period, targets for mandatory procurement and quotas were controlled by a state marketing board. In 1995, the Governor's Grain-Bag Responsibility System was installed with the goal of stimulating production, stabilizing prices, increasing grain stocks, reducing imports, and ensuring supplies for urban areas and the military. In 1998, a policy change allowed individuals and private companies to procure grain from wholesale and retail markets, but continued to maintain procurement from farmers under state control. This was implemented with the goal of reducing the central government's fiscal burden in financing marketing and stockpiling (Rozelle, Huang, and Jin 2000; Huang and Rozelle 2002). These reforms led to record levels of production and increasing stocks, and by the late 1990s, average annual wheat imports fell below 1 million tons – down from 10 million tons in the early 1990s (FAOSTAT 2004). Other factors affecting China's wheat market were the assessment of a 13 percent value-added tax at the border, and a 1 percent import duty, thus making imported wheat uncompetitive in some years (Mitchell and Mielke 2005).

With this heavy intervention in three of the largest import markets, it makes sense to try to represent some of these importer policies in the model. This can potentially improve the results for not just importers, but for exporters as well. If major import markets are insulating their consumers from price changes, this will tend to destabilize the wheat prices faced by exporters. The latter would help predicted and observed values to converge for North America and Argentina. Thus we now turn to one relatively simple way of incorporating such policies into the model.

Representing the Impact of Policy on Volatility
Ideally, wheat policies should be modeled explicitly, but this is very difficult, as this may involve a large number of domestic as well as border policies. Indeed, the policies themselves are sometimes deliberately unclear, such as in the case of state marketing boards. There are also instances in which policies are explicitly stated but not followed, such as with price stabilization schemes.

Incomplete price transmission can also arise from a wide range of unrelated factors such as: transaction costs, market power, non-constant returns to scale, product homogeneity, and changes in exchange rates (Conforti 2004).

Instead of trying to incorporate all of these aspects into the model, the alternative pursued here is to estimate *price transmission elasticities*. These summarize the effect of domestic and border policies and the many other phenomena that determine the link between world and domestic prices. Price transmission elasticities were first proposed by Bredahl, Meyers and Collins (1979) to measure incomplete adjustment in domestic prices in response to changing world prices as a single parameter. They have since been used in other studies of wheat markets, such as Tyers and Anderson (1988) and Devadoss and Meyers (1990). A discussion of their use for policy representation in global models is found in Conforti (2004) and in van Tongeren, van Meijl, and Surry (2001).

We follow the lagged price transmission specifications of Abbott (1979) and Collins (1980) to formulate a relationship between changes in international prices and domestic prices. Since the GTAP model incorporates Armington national product differentiation, the price transmission elasticities operate in addition to this feature of the CGE model. We are interested in *short-run* price transmission elasticities given the nature of the annual shocks considered within the stochastic CGE experiment. The econometric specification is autoregressive, and takes the form of a *partial adjustment model* in which incomplete transmission arises from policy and institutional rigidities (Abbott 1979, p. 24):

(7) $\ln PD_t = \alpha + \lambda \ln PD_{t-1} + \beta \ln PW_t + \varepsilon_t$.

PD_t is domestic price at time t, PW_t is world price, and $\beta = (\partial \ln PD)/(\partial \ln PW)$ is a short-run price transmission elasticity that indicates how much of a given change in the world wheat price is transmitted to the domestic price in the current period. The error term (ε) is assumed to be identically, normally, and independently distributed. Due to violations of the classic linear regression model, OLS estimation of equation (7) may give rise to biased estimates in small samples. However, since (7) is a partial adjustment model, OLS estimators maintain the relatively more important properties of consistency and efficiency (see Greene 2004, p. 568).

In line with our validation criterion, we examine annual data for the 1990-2001 period. Domestic prices are from FAOSTAT (2004) and represent the prices received by producers. The U.S. *f.o.b.* average Gulf port price serves as a proxy for the world price.

Given the time-series nature of the data, we might ideally first investigate the dynamic properties of the price series through unit root and cointegration tests, followed by the possible adoption of an error correction model (as in Conforti 2004). A key limitation, however, is that our annual price series covers 11 years only. This limits our ability to test the dynamic properties of the series and to test for serial correlation through a Breusch-Godfrey approach or similar method. Given these considerations, we resort to plotting the residuals from OLS regressions of (7) with respect to each regressor. Although this does not provide conclusive evidence, serial correlation appears to be quite minor for nearly all regions.

More importantly, the OLS results turn out to be quite consistent with the findings of the previous studies mentioned above. Parameter estimates of equation (7) are reported in table 4, with standard errors in parenthesis. For our validation work we seek only price transmission elasticities for the seven net *importing* countries, since this should automatically generate increased price volatility for exporters (as highlighted in previous section). Nevertheless, we also estimate equation (7) for the six net exporters to demonstrate the usefulness and reliability of the approach.

Table 4 shows that – as expected – relatively high elasticities prevail in net exporting countries, with estimates of β ranging from 0.508 to 1.130 for Argentina, Australia, Canada, Mexico, USA, and Other Europe. By contrast, the net importing countries have low levels of transmission. With the exception of Brazil's relatively high estimate of 0.733, estimates of β for the net importers range from only 0.005 to 0.515. The extremely low value for Japan (0.005) shows almost complete insulation of domestic prices with respect to variation in international prices. The results for China and the EU

give empirical evidence of the market disconnection induced by border policies in those countries over this historical period.

The magnitudes of the estimated elasticities for the selected importing regions support their incorporation into the CGE model. This is carried out by combining the price transmission function used in the econometric estimation (7) with the CGE price linkage equations between domestic and world prices. These are expressed in percentage change terms (denoted by lower case variables) and take the form:

(8) $pd = pw + t$,

where $pd = (dPD/PD)100 = (d \ln PD)100$, and $pw = (dPW/PW)100 = (d \ln PW)100$. This may be solved for the equivalent endogenous percentage change in the *ad valorem* tariff response function, which serves to dampen the impact of world price changes on the domestic market:

(9) $t = (\beta - 1)pw$.

Thus the price transmission elasticities are incorporated into the CGE model as follows: $pd = \beta(pw)$.

The rightmost column of table 3 reports how inclusion of the price transmission elasticities for net importers (denoted with the superscript ^{IMP}) affects price volatility in each region. In comparing these results to those of the standard GTAP model it suggests that inclusion of the estimated price transmission elasticities improves this measure of performance. In most of the cases the performance is weakly better when price transmission elasticities are used for importers. Another perspective is gained by comparing the correlation between the simulated and observed standard deviation of price changes for the eight countries having a specific result on observed price volatility. Under the standard model this correlation is 0.284, but with the inclusion of the price transmission elasticities, the correlation increases to 0.367.

Note that the model's performance improves for net importers like Japan and South Asia, as well as for exporters, even though the exporters' price transmission elasticities are left at unity according to the design of the experiment. For example, the U.S. observed price volatility is 15.8. The standard GTAP model generates a simulated price volatility of 11.5, but the simulated price volatility rises to 13.7 when price transmission elasticities for net importers are implemented. In effect, the disconnection between domestic and international prices in *import* markets tends to increase price variability for exporters. This is an improvement that is consistent with what was learned from the pattern of bias in figure 2.

Could we do better? The answer is most certainly yes. In addition to modeling wheat policies explicitly, more effort could be invested in modeling wheat producer and purchaser behavior. However, our point here is to offer a standardized means for validating a CGE model, and to demonstrate how this can reveal problematic features of a specification that might otherwise go unnoticed.

Conclusions

This study proposes an approach to validating simulation models, on a sector-by-sector basis, with particular emphasis on agricultural markets. We focus on the world wheat market and subject a global CGE model (GTAP) to a validation test by using the model's capacity to replicate price volatility as the evaluation metric. While the model performs reasonably well for some regions of the world, it is impossible to definitively validate

such models, as noted by Gass (1983). Instead, we focus on key areas in which the model fails, or appears to be *invalid*. Here, we find that the model tends to under-predict price volatility for net exporters, and over-predict volatility for importing regions.

This finding turns out to be very useful for understanding how to improve the model. The pattern of failure suggests that we focus on the incomplete transmission of world wheat price signals into the domestic markets of the major importing countries. We find substantial evidence of such incomplete transmission. When this feature is incorporated into the CGE model it improves the correlation with observed price volatility. This is because the disconnection between domestic and international prices in *import* markets tends to increase price variability for exporters. This issue might have gone unnoticed without the type of validation proposed in this article.

We conclude that the inadequate representation of government policies for wheat, including the presence of state trading corporations, is an important limitation of the GTAP global CGE model – and likely many similar models. Future efforts to improve this representation would greatly enhance the validity of such models, and their usefulness in policy analysis.

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Table 1. Selected Estimates of Autoregressive Moving Average, equation (1), 1966-2002

	Autoregressive Factors (ϕ_i)	Moving Average Factors (θ_j)	R^2
Argentina	$\phi_1 = 0.697$		0.487
Australia	$\phi_1 = -1.034$, $\phi_2 = -0.071$, $\phi_3 = 0.577$	$\theta_1 = -1.605$, $\theta_2 = 0.986$	0.373
Brazil	$\phi_1 = 0.765$		0.576
Canada	$\phi_1 = 0.497$, $\phi_2 = 0.346$	$\theta_1 = -0.315$, $\theta_2 = 0.589$	0.532
China	$\phi_1 = 0.977$		0.946
Japan	$\phi_1 = 1.865$, $\phi_2 = -0.944$	$\theta_1 = 0.959$, $\theta_2 = -0.155$	0.881
Mexico	$\phi_1 = 0.619$, $\phi_2 = 0.248$		0.662
United States	$\phi_1 = 0.788$		0.558
European Union	$\phi_1 = 0.987$	$\theta_1 = 0.360$	0.886
Mid. East & No. Africa	$\phi_1 = 0.986$	$\theta_1 = 0.462$, $\theta_2 = -0.105$	0.879
Other Europe	$\phi_1 = 0.660$		0.423
Sub-Saharan Africa	$\phi_1 = 0.837$		0.593
Rest of Latin America	$\phi_1 = 0.846$		0.724
South Asia	$\phi_1 = -0.201$, $\phi_2 = 0.264$, $\phi_3 = 0.496$		0.971

Table 2. Characterizing Wheat Production Variability for Simulation Model

Region	Normalized standard deviations of residuals	Triangular distribution of production (1966 to 2002, million tons)		
		Lower endpoint	Mean	Upper endpoint
Argentina	24.12	4.07	9.95	15.83
Australia	28.33	4.45	14.54	24.63
Brazil	33.87	0.45	2.63	4.81
Canada	18.34	12.19	22.14	32.08
China	9.82	54.83	72.20	89.56
Japan	14.01	0.42	0.64	0.85
Mexico	16.20	1.96	3.24	4.53
United States	13.04	38.52	56.61	74.70
European Union	9.16	57.01	73.50	89.99
Mid. East & No. Africa	10.54	27.10	36.53	45.96
Other Europe	14.87	19.11	30.05	41.00
Rest of Latin America	12.16	1.52	2.17	2.81
South Asia	8.35	44.75	56.26	67.76

Note: The endpoints are calculated as Mean $\pm\sqrt{6V}$, where V is the variance of the residuals. Normalized standard deviation of the residuals is calculated as $100\sqrt{V}$/Mean. Validation is conducted for these 13 regions only because remaining 4 regions in Appendix Table A1 lack data on production and/or prices.

Table 3. Comparison of Observed and Model-Generated Price Volatility

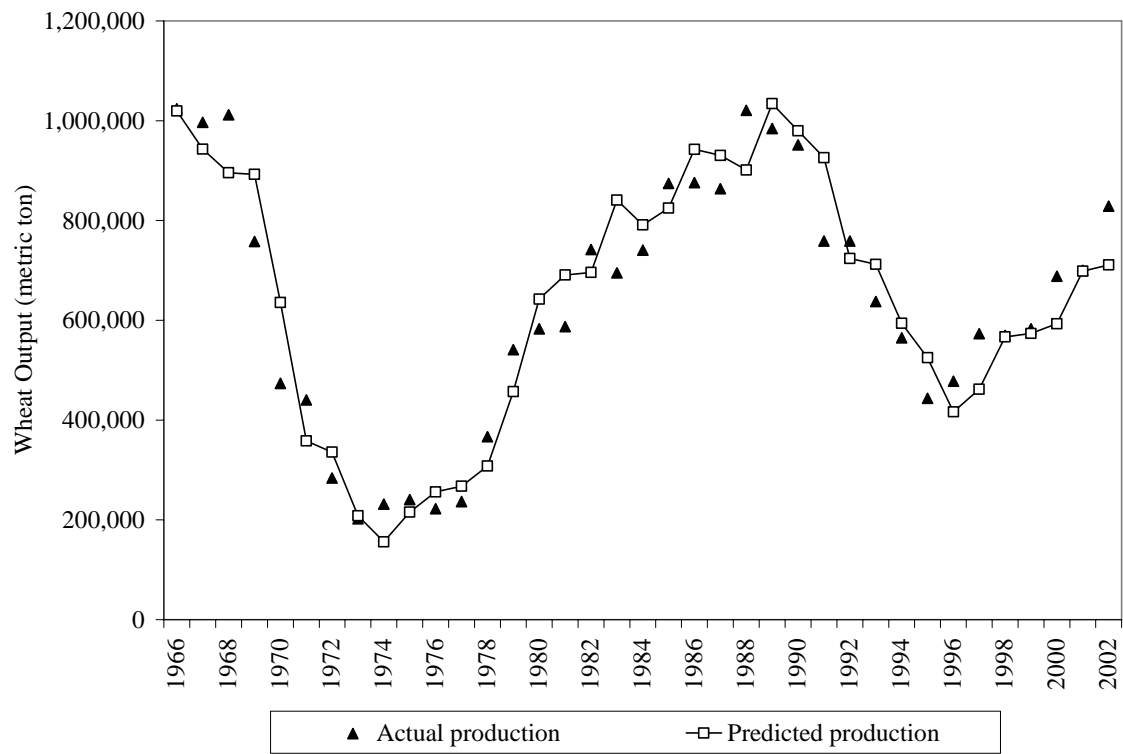| Region	Observed standard deviation of price changes		Simulated standard deviation of price changes	
	Nominal	Real	Standard GTAP model	With price transmission elasticities for selected importers
Argentina	34.5	34.4	26.7	29.4
Australia	16.5	21.4	25.6	31.7
Brazil *IMP*	26.8	15.5	44.5	44.7
Canada	14.9	16.6	14.8	17.5
China *IMP*	21.4	14.5	17.6	17.7
Japan *IMP*	3.6	3.4	12.4	12.2
Mexico	34.2	22.3	15.2	16.1
United States	16.3	15.8	11.5	13.7
European Union *IMP*	5.9 - 8.2	5.9 - 7.8	9.1	9.6
Mid. East & No. Afr. *IMP*	4.2 - 29.1	4.9 - 10.4	10.4	10.4
Other Europe	19.9 - 28.0	18.6 - 41.7	18.5	18.6
Rest of Latin America *IMP*	8.9 - 29.7	9.0 - 36.6	12.2	12.3
South Asia *IMP*	7.2 - 10.4	7.1 - 8.8	11.5	10.5
Correlation between simulated and observed			0.284	0.367

Notes: Source of actual standard deviation of annual wheat price changes is FAO. The symbol (*IMP*) is used to denote the net importers for which a table 4 price transmission elasticity is implemented in the second validation experiment.

Table 4. Estimation of Short-Run Price Transmission Elasticities (equation 7)

	α	λ	β	R^2
Argentina	-1.090 (1.279)	0.001 (0.208)	1.130* (0.252)	0.766
Australia	0.076 (0.746)	0.075 (0.133)	0.902* (0.145)	0.879
Brazil ^{IMP}	0.609 (0.864)	0.128 (0.176)	0.733* (0.156)	0.820
Canada	0.699 (0.765)	0.058 (0.192)	0.740* (0.154)	0.843
China ^{IMP}	-0.581 (1.092)	0.603* (0.166)	0.515* (0.157)	0.787
Japan ^{IMP}	3.465 (2.714)	0.517 (0.583)	0.005 (0.425)	0.273
Mexico	3.054 (1.813)	-0.085 (0.309)	0.508 (0.268)	0.341
USA	-0.452* (0.154)	0.075 (0.035)	0.983* (0.037)	0.995
European Union (France) ^{IMP}	-0.585 (0.934)	0.795* (0.205)	0.314 (0.227)	0.849
Mid. East & No. Africa (Egypt) ^{IMP}	-1.364 (1.883)	0.986* (0.251)	0.290 (0.155)	0.696
Other Europe (Hungary)	0.975 (1.865)	-0.050 (0.277)	0.765* (0.328)	0.441
Rest of Latin America (Peru) ^{IMP}	1.634 (1.027)	0.286 (0.225)	0.457* (0.154)	0.756
South Asia (Pakistan) ^{IMP}	-0.153 (2.329)	0.781 (0.392)	0.251 (0.147)	0.425

Notes: β is the price transmission elasticity and result of key interest. Standard errors are in parenthesis. Asterisk (*) implies coefficient is statistically different from zero at 5% level of significance. The estimated price transmission elasticity is implemented in the second validation test only for net importers, denoted by (^{IMP}).

Figure 1. ARMA model of Japanese wheat production
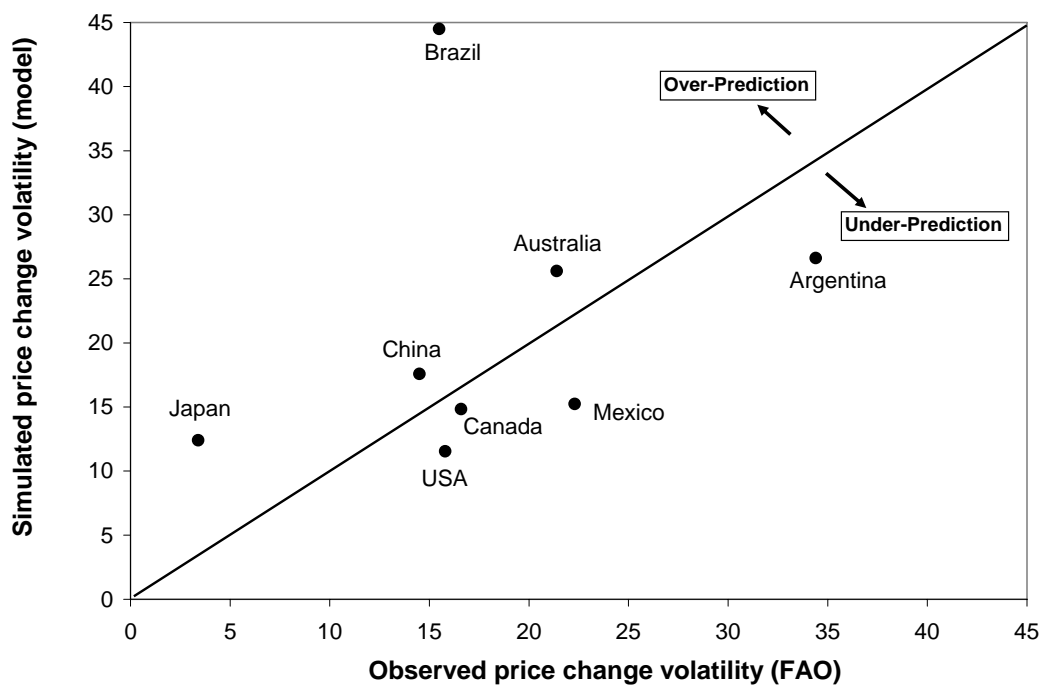
Figure 2. Plot of simulated on observed standard deviation of price changes

Notes: Source is columns 2 and 3 of table 2. Simulated results correspond to the standard version of GTAP, that is, the version without price transmission elasticities.

Appendix Table A1. Regional aggregation

No.	Regions	Original 66 GTAP regions
1	Argentina	Argentina
2	Australia	Australia
3	Brazil	Brazil
4	Canada	Canada
5	China	China
6	Japan	Japan
7	Mexico	Mexico
8	United States	United States
9	European Union	Austria; Belgium; Denmark; Finland; France; Germany; United Kingdom; Greece; Ireland; Italy; Luxembourg; Netherlands; Portugal; Spain; Sweden
10	Middle East & North Africa	Rest of Middle East; Morocco; Rest of North Africa
11	Other Europe	Switzerland; Rest of Eur Fr; Albania; Bulgaria; Croatia; Czech Republic; Hungary; Malta; Poland; Romania; Slovakia; Slovenia; Estonia; Latvia; Lithuania; Cyprus; Turkey
12	Rest of Latin America	Central America; Colombia; Peru; Venezuela; Rest of Andean Region; Chile; Uruguay; Rest of South America
13	South Asia	Indonesia; Malaysia; Philippines; Singapore; Thailand; Vietnam; Bangladesh; India; Sri Lanka; Rest of South Asia
14	Sub Saharan Africa	Botswana; Rest of South Africa; Malawi; Mozambique; Tanzania; Zambia; Zimbabwe; Other Southern Africa; Uganda; Rest of Sub-Saharan Africa
15	Other East Asia	Hong Kong; Korea; Taiwan
16	Russia	Russian Federation; Rest of Former Soviet Union
17	Rest of World	New Zealand; Rest of World

Note: Validation is not conducted for regions 14 - 17 for lack of data on prices and/or production.

Appendix Table A2. Sectoral aggregation

No.	Sectors in this study	Original 57 GTAP sectors
1	Paddy rice	Paddy rice
2	Wheat	Wheat
3	Cereal grains nec	Cereal grains nec
4	Vegetables, fruit, nuts	Vegetables, fruit, nuts
5	Oil seeds	Oil seeds
6	Sugar cane, sugar beet	Sugar cane, sugar beet
7	Plant-based fibers	Plant-based fibers
8	Crops nec	Crops nec
9	Cattle,sheep,goats,horses	Cattle,sheep,goats,horses
10	Other Animal products nec	Animal products nec
11	Raw milk	Raw milk
12	Wool, silk-worm cocoons	Wool, silk-worm cocoons
13	Fishing	Fishing
14	Coal, Oil, Gas, Minerals	Coal; Oil; Gas; Minerals nec
15	Meat: cattle,sheep,go.,ho.	Meat: cattle,sheep,goats,horse
16	Other Meat products nec	Meat products nec
17	Vegetable oils and fats	Vegetable oils and fats
18	Dairy products	Dairy products
19	Processed rice	Processed rice
20	Sugar	Sugar
21	Food products nec	Food products nec
22	Bev. and tobacco products	Beverages and tobacco products
23	Manufacturing	Forestry; Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Petroleum, coal products; Chemical,rubber,plastic prods; Mineral products nec; Ferrous metals; Metals nec; Metal products; Motor vehicles and parts; Transport equipment nec; Electronic equipment; Machinery and equipment nec; Manufactures nec
24	Services	Electricity; Gas manufacture, distribution; Water; Construction; Trade; Transport nec; Sea transport; Air transport; Communication; Financial services nec; Insurance; Business services nec; Recreation and other services; PubAdmin/Defence/Health/Educat; Dwellings

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[1] Data and model files allowing straightforward replication of this work by others are available at www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1875