Incorporating Commodity Stockholding Behavior into a Short-run General Equilibrium Model of the Global Economy

Thomas W. Hertel*
Purdue University

Jeffrey J. Reimer
University of Wisconsin-Madison

Ernesto Valenzuela
Purdue University

Prepared for presentation at the joint meetings of the *American Agricultural Economics Association*, *Canadian Agricultural Economics Society*, and *Rural Sociological Society*, July 27-30, 2003, Montreal, Quebec.

* Contact author: Department of Agricultural Economics, Center for Global Trade Analysis, Purdue University, 403 W. State St., West Lafayette, IN 47907-2056. Phone: (765) 494-4199. Email: hertel@purdue.edu.

Introduction

Computable General Equilibrium (CGE) models are increasingly used for agricultural trade policy analysis (Francois and Shiells on NAFTA, 1994; Martin and Winters on the Uruguay Round, 1997; Burfisher et al., 1998; OECD, 2002). One of the questions that frequently arises in such applications is: What is the time frame for the results? Comparative static CGE analyses of agricultural trade typically have a “medium run” closure of two to five years, depending on the specific factor market assumptions employed. Most dynamic CGE models focus on long run growth effects, not short run dynamics. Thus this literature tends to have little to say about short run issues of one year or less. Yet the one year time frame is what many policy analysts typically have in mind.

The problem with short run analysis is that the many “equilibrium” assumptions implicit in most CGE models are typically violated, particularly so if one looks at time frames of one year or less. Perhaps the most overt mis-characterization is that the holding of agricultural commodity stocks is completely assumed away in most CGE analyses. Changes in stocks are typically either eliminated within the initial data (e.g., Dimaranan and McDougall, 2002), or subsumed into aggregate investment. Yet the adjustment of stocks is one of the most important means of accommodating short run volatility in agricultural commodity markets (Williams and Wright, 1991). Therefore, this study introduces a simple model of commodity stockholding behavior that can be readily incorporated into a CGE model. This study also demonstrates how to validate the model against historical data for the staple grains sector, the year-to-year output of which is highly variable due to weather volatility. The result is a CGE formulation that is useful for addressing issues that are short run in nature. It may also be useful for analysts who wish to explore the nature of price stabilization schemes that are intended to benefit the poor in developing countries, for whom staple grains comprise not only a large share of the household budget, but also an important share of farm income for families living in rural areas.

The rest of the paper is organized as follows. In the following section, a two period model of stockholding is presented to identify the basic economic relationships involved. We then present a simple stockholding function that is consistent with the results of this optimization model. It is nonlinear and captures the fact that there are physical limits to annual changes in stocks. In the next section, this stockholding model is estimated for U.S. wheat, using data from the Food and Agriculture Organization (FAO). This demonstrates the realism and flexibility of the proposed functional form, and also provides a basis for calibrating the stockholding model for those regions lacking adequate data. The subsequent section presents preliminary results regarding the calibration and validation of the stockholding model within the CGE model. The final section summarizes and concludes.

A simple model of stockholding behavior

This section presents a simple yet realistic model of stockholding behavior associated with staple grains markets. In practice, such a commodity can be stored by private sector agents (e.g., producers, consumers, middlemen, or merchants) or by a public authority. In either case the agent is likely to be motivated by the economic incentives captured in the following model. Consider, as do Newbery and Stiglitz (p. 195), an agent who maximizes utility over two periods. The agent receives income Y_t at time *t*, and can either store some amount of grain (*S*) or can lend a certain amount of income to another agent (*L*) for a fixed return, (1 + *r*). The price of staple grains in time *t* is p_t, and storage of staple grains (*S*) from period *t* to *t* + 1 is costless. The agent can also release grains such that $S < 0$.[1] The future price of grains, p_{t+1}, is an expected value, and the agent is assumed to be risk neutral. The utility of the second period, *t* + 1, is weighted by a subjective discount factor, β. The objective function of the agent is then:

$$\underset{L,S}{Max}\ W = U\{Y_t - p_t S - L\} + \beta U\{Y_{t+1} + p_{t+1}S + (1+r)L\} \qquad (1)$$

Maximizing (1) requires setting the partial derivatives of *W* with respect to lending (*L*) and storage (*S*) equal to zero:

$$\frac{\partial W}{\partial L} = -U' + \beta(1+r)U' = 0 \qquad (2)$$

$$\left.\begin{aligned} \frac{\partial W}{\partial S} = -p_t U' + p_{t+1}\beta U' \le 0 \\ S \ge 0 \end{aligned}\right\} \text{ Complementary inequalities} \qquad (3)$$

---

[1] This may happen if the agent has some initial stocks of grain, not explicitly identified in the objective function (1), or if the agent has access to a futures market where it is possible to go short in a commodity, letting someone else do the physical storing.

Solving (2) we find that the subjective discount factor is equal to the fixed return on lending ($\beta = 1 + r$). This can be substituted for β in (3), in which we have a set of "complementary inequalities" whereby strict inequality of one implies equality of the other (Newbery and Stiglitz, p. 196). In (3), therefore, the product of (S) with ($-p_t U' + p_{t+1}\beta U'$) must always be zero. If we have an situation whereby:

$$p_t < \frac{p_{t+1}}{1+r} \tag{4}$$

such that the purchase price of grains in period t is less than the price of grains in period t+1, normalized by the return associated with the lending alternative to stockholding, then agents. If (4) occurs when $S = 0$, agents will wish to stockpile (i.e., $S > 0$) up to the point where:

$$p_t = \frac{p_{t+1}}{1+r}. \tag{5}$$

If, on the other hand, the cost of buying grain to store from period t to t+1 is greater than the payoff in period t+1 normalized by the payoff from lending, we have:

$$p_t > \frac{p_{t+1}}{1+r}. \tag{6}$$

This will cause agents to sell off stocks (i.e., $S < 0$) up to the point at which relationship (5) is once again restored. Thus there are economic incentives for agents store grain across periods in anticipation of a rising price, and to release stocks of grain in anticipation of a falling price, thereby helping to stabilize prices (Newbery and Stiglitz).

As is often the case in economics, this simple framework does not give rise to a particular functional form for empirical work. One form of stockholding behavior that is consistent with the economic relationships established above is:

$$\hat{S} = \frac{\hat{S}_{\max}\left(e^{c\hat{p}} - 1\right)}{\left(e^{c\hat{p}} + 1\right)}, \qquad (7)$$

where:

$\hat{S}$ is the change in stocks relative to production in one period,

$\hat{p}$ is the proportional change in grains price from one period to the next,

c is a parameter governing stockholding response to price changes, and

$\hat{S}_{\max}$ is the maximum possible change in stocks relative to production, across periods.

This functional form has several advantages for the present analysis.[2] First, it explicitly recognizes that stockholding is not so perfect that it completely dampens price variation across periods. In particular, there are exogenous capacity constraints, as represented by $\hat{S}_{\max}$, dictating the maximum stockholding activity that is feasible from one period to the next:

$$-\hat{S}_{\max} < \hat{S} < \hat{S}_{\max}.$$

---

[2] This exponential function was inspired by Dixon and Rimmer's (2002) general equilibrium modeling of sector-specific change in capital stocks. Thanks are due to Robert McDougall for proposing this approach.

Equation (7) also allows for estimation of the stockholding response to a given price change, as embodied in the parameter $c < 0$. As *c* approaches zero from below, the response of stockholding to a price change diminishes. On the other hand, as *c* gets larger in absolute value ($c \to -\infty$), the stockholding response to a given price change gets stronger. If $c = 0$ or if $\hat{p} = 0$ (i.e., no price change), then there is will be no change in stocks ($\hat{S} = 0$) in this formulation.

Equation (7) can also be expressed in linear-log form, with the proportional price change isolated on the left hand side of the equation:

$$\hat{p} = \frac{1}{c}\left[\ln\left(\hat{S}_{\max} + \hat{S}\right) - \ln\left(\hat{S}_{\max} - \hat{S}\right)\right] \qquad (8)$$

We obtain the maximum stock change ($\hat{S}_{\max}$) by observing the maximum absolute value of stock changes historically, relative to historical production. The parameter *c* can be estimated, and this is the topic of the next section.

Data and estimation

To estimate *c* directly, (8) is rearranged so that the change in stocks is on the left hand side. A normally, independently distributed error term (ε_t) is added to the expression, yielding the equation (9):

$$\ln\left(\frac{\hat{S}_{\max} + \hat{S}_t}{\hat{S}_{\max} - \hat{S}_t}\right) = c\hat{p}_t + \varepsilon_t\,. \qquad (9)$$

The subscripts (t) represent time period t. Data are from FAOSTAT (2003), and concern annual U.S. wheat production, stock changes, and prices between 1966 and 1995 (30 observations). Prices are at the producer level and are reported in nominal US$ values. An Augmented Dickey-Fuller test indicates the price time series is non-stationary. It is found that first differencing of the data (i.e., $p_t - p_{t-1}$) makes the series stationary. Since transforming the price data into percentage changes has the same effect, we calculate the dependent variable to be a percentage price change: $\hat{p}_t = (p_t / p_{t-1}) - 1$.[3] Relative stock changes ($\hat{S}_t$) are calculated as the stock change in period t, divided by domestic production in t. Between 1966 and 1995, the maximum absolute value of $\hat{S}_t$ is 0.38. $\hat{S}_{\max}$ is fixed at a slightly larger value (0.50) to allow some leeway. Since $\hat{S}_{\max}$ will never be actually observed.[4]

The parameter c is estimated to be –1.48 when (9) is regressed with ordinary least squares. The standard error is 0.29 and the associated t-statistic is –4.95. A one-sided hypothesis that $c \geq 0$ is rejected at the 1% level of significance. An R^2 of 0.47 indicates almost half the variation in stockholding behavior is explained by this simple model.

---

[3] One observation is lost in this process.

[4] Note that price changes are exogenous in this model. While this is clearly a limitation, some support is offered by the fact that wheat is widely traded and the U.S. is a small player on the world market as a whole (its average share of 1966-1995 world production is 12.8%). Another key assumption of our approach is that stockholding behavior is constant over time (i.e., there is no stockholding regime change).

Figure 1 plots the data, and also the fitted points associated with the estimated parameters. The latter correspond to setting c = –1.48 and $\hat{S}_{\max} = 0.5$ in equation (7). Examination of Figure 1 suggests the model fits the observations quite well. Note that the fitted function goes through the origin (by construction). This implies that stocks remain fixed when prices do not change.

Future research will need to be directed toward estimating this relationship for other regions and commodities. This is complicated by problems of aggregation, as well as evidence of regime changes in many cases (e.g., Zambia in the late 1970s, to name just one example).

CGE model, closure, and aggregation

The CGE model that we work with is a modified version of the widely used Global Trade Analysis Project (GTAP) model (Hertel, 1997). This model has the advantage of offering global coverage of staple grains production and consumption, along with bilateral trade. We introduce stockholding as an alternative form of investment in the model. Like other forms of investment in the static GTAP formulation, it is financed by savings. Production functions in the standard GTAP model exhibit constant returns to scale and are of the nested constant elasticity of substitution (CES) form, with land, labor and capital substituting for one another in a value-added aggregate, and composite intermediates substituting for value-added at the next CES level. Since the focus in this paper is on staple grains production and consumption, and since these grains are used as a feedstuff in many countries, we modify the livestock production functions to better capture the substitution possibilities in feed demand. Specifically, we introduce another CES nest into the livestock production functions in which feed (grains, other agricultural products, and processed food by-products) are combined with non-feed inputs to produce a finished livestock product.

The GTAP version 5.0 data has 66 regions and 57 commodities, and these are aggregated to the 15 sectors and 13 regions displayed in Appendix Tables 1 and 3, respectively. The aggregation scheme for regions is based primarily on geographical proximity, and broadly reflects the regional groupings employed by FAO statisticians. The FAO typically aggregates commodities according to similarity in end use, and staple grains is one of the aggregate categories. Appendix Table 2 provides a precise description of what is encompassed by staple grains and how this is concorded to the GTAP data base. FAO data on staple grains production and stockholding was obtained for the country groupings used in the GTAP analysis. In the case of the price data, we face a problem of aggregation. Therefore, when it comes to comparing model results with observed price changes, we refer to a range of price changes based on important country-commodity combinations in the region.

Calibration of the stockholding model

It has been shown that the stockholding specification (9) can be successfully estimated. However, it is quite difficult to obtain quality, appropriately aggregated price data for estimation of (9) for most of the regions in our model. For this reason an alternative, second approach to identifying the parameters of the model is pursued:

Calibration. Our approach is similar to that of macroeconomists who study the real business cycle, such as Kydland and Prescott (1996) and Hodrick and Prescott (1997). They calibrate a model by setting parameter values equal to the average values of time series summary statistics known to have changed little over time. A computer simulation produces output from a macroeconomic model, and adjustments are made to the parameters until the output from these simulations has characteristics that are qualitatively similar to those observed in the real world (Kennedy 1998, p. 9). Qualitative criteria include means, standard deviations, and correlations. Once the parameter adjustments are finalized, the model is simulated to address the questions of interest. Our approach is consistent with this, but instead of examining economy-wide phenomena like the macro-economists, we focus on a single sector of the economy: staple grains. Its variation in supply from year to year provides a series of natural experiments with which to validate the demand side of the model.

Our approach also draws inspiration from the earlier work of Tyers and Anderson (1992), as well as Vanzetti (1998), who model uncertainty in world food markets by sampling from a distribution of supply shocks. We make use of the Gaussian Quadrature approach outlined in DeVuyst and Preckel (1997), and sample from an estimated distribution of staple grains production in twelve regions over the 1966-1995 period.[5] This is implemented in the GTAP model, by treating production of staple grains as pre-

---

[5] The following section outlines how we characterize the distribution of staple grain yields.

determined, and then shock output directly.[6] In employing Stroud's quadrature, we assume that the simulation results are well approximated by a third-order polynomial in the varying parameter, and that the parameter has a symmetric distribution. This and other properties of Gaussian Quadrature enable the CGE model to be simulated relatively few times while still replicating the spectrum of outcomes associated with a similarly fashioned Monte Carlo process. For each of these outcomes the model is simulated using a short run factor market closure[7], and percentage staple grains price changes are generated for each region. Our benchmark is the standard deviation of stock ratio changes for each region. We calibrate the stockholding parameter "c" to replicate observed changes in this stock ratio. The model is subsequently validated by comparing the standard deviation of percentage price changes produced by the model, with those observed for staple grains in the region in question.

Characterizing short-run volatility in staple grain production

A key step in the calibration process is to characterize volatility in staple grain production. In particular, a distribution of production outcomes over time needs to be estimated. The general approach of Vanzetti (1998) is followed. Vanzetti examines wheat production between 1960 and 1994, and observes that while production levels have been trending upward steadily over time, there is a great deal of year-to-year variation

---

[6] In GTAP terminology, we "swap" "profitslack" with "qo" for staple grains, and shock the variable "qo".

[7] In this closure, capital, land, and natural resources are sector specific, and agricultural labor mobility is defined based on OECD estimates.

due largely to yield variability. He finds the short run variability is best characterized by fitting a linear trend line to production values over time. Our analysis of Food and Agriculture Organization data (FAOSTAT, 2003) corroborates this approach. Year-to-year variations in staple grain production reflect supply side rather than demand side volatility, and much of the supply side variation is weather-induced as opposed to deriving from year-to-year changes in acreage. To characterize year-to-year instability while abstracting from the increasing trend in production over time, we follow Vanzetti and estimate a linear trend model for individual regions. Figure 2 illustrates this estimation in the case of U.S wheat production. We focus on the residuals of these regressions, assuming them to be normally distributed. Using the mean level of production over this period and the standard deviation of residuals, a symmetric, triangular distribution is formed for staple grains production in each region. The Gaussian Quadrature approach (discussed above) is applied to obtain the resulting mean and standard deviation for endogenous variables of interest.

Calibration of the stockholding function

This section presents preliminary results from the staple grains calibration exercise. For each region, the stockholding function's slope parameters (c) are calibrated to mimic the observed variation in regional stocks ratios. In particular, c values are adjusted until GTAP outcomes match the actual standard deviations of yearly stock changes normalized on production, calculated with FAO data. Results are presented in Table 1. Actual, observed standard deviations in stocks relative to regional production are in column 2. Simulation-based standard deviations (i.e., *ex post* values) are in column 3. Table 1's rightmost column indicates the *c* parameter associated with column 3. The calibration exercise is quite successful in the sense that the model allows us to replicate the regional variability in the stocks changes to production ratios (values of column 2 are quite consistent with those of column 3). This suggests the stockholding model and slope parameter provides a flexible, effective lever for orienting a CGE model toward the short run.

One notes, however, that the *c* values of Table 1 are all much larger than the earlier, econometrically estimated value of -1.48 for U.S. wheat. Some of this can be attributed to the fact that different countries are represented in the aggregation in the model. However, the large size of the *c* values indicates that the stockholding model must be made extremely sensitive to price variation in order to obtain the stockholding responses observed in FAO data.

The most likely explanation for this finding is that there is too little price variation in the model. The reasoning is as follows. If the price volatility associated with supply shocks is limited, then volatility in stocks will also be low for the estimated value of *c* in the case of U.S. wheat, for example. Thus, with too little price variation in the model, the absolute value of *c* must be raised in order to elicit the desired stockholding variation. If this line of reasoning is correct, then the next step of this project should be to search for the underlying reasons why the short run price volatility is too low in our model. An obvious place to focus (and a topic for a future version of this paper) is to systematically examine the model's demand, feed use, and trade elasticities. Excessively high elasticities would dampen price volatility, providing little impetus for stocks to change. It is likely that some of these elasticities need to be made more inelastic for looking at short run phenomena. This suggests a broader approach to calibration involving not only stockholding but also the behavior of imports, feed demand and consumer demand.

These findings are reinforced when one examines actual versus model-generated standard deviations of staple grains price changes (Table 2). As noted earlier, it is difficult, if not impossible, to obtain a meaningful price series for regional, staple grains aggregates. For this reason, column 2 of Table 2 presents a *range* of standard deviations associated with the individual commodities of particular countries (as before, these are all based on FAO data). Column 3 displays the standard deviation of percentage price changes arising from the GTAP simulation. Here, the calibrated *c* values of Table 1 have been used. While these values of *c* worked well in terms of replicating the observed variability in stock changes (even if they were unexpectedly high), they do not work as well when *price variability* is used as the qualitative criterion. A comparison of columns 2 and 3 in Table 2 suggests that there is not as close a correspondence as was seen in Table 1. Often, the actual observed standard deviation tends to be larger.

What would it take for the model's simulated price changes to become more like those that are seen in reality? If the stockholding parameters are set equal to zero, then there is *no* stockholding response, and more price variability should result. The rightmost column of Table 2 presents the model-generated standard deviation of percentage price changes in this scenario (i.e., when $c = 0$ for each region). With no stockholding at all it appears that the price volatility of the model is closer to the observed volatility in some cases. However, setting $c = 0$ is entirely inconsistent with the results of Table 1. In other words, we have not managed to *simultaneously* reconcile model results with reality for both price *and* stocks changes. As indicated earlier, mis-specified short run consumer demand, feed use, or trade elasticities in the GTAP model are likely what give rise to this conundrum. This suggests the importance of broadening our calibration approach to include these other parameters.

Preliminary conclusions

One of the most vexing problems facing economists drawing on CGE models is the lack of validation for such models. This is especially problematic in applications relating to agricultural policies, since the time frame for such analyses is often one year, and CGE models are typically specified with a medium term (two to five year) time frame in mind. In the short run, stock-holding behavior is a significant factor in determining price volatility, and it is notably absent in most CGE models. This paper contributes to resolving this gap in the literature in two ways. Firstly, it introduces a stockholding relationship into one of the most widely used CGE models of global trade – the GTAP model. This relationship is estimated econometrically for one region, and calibrated based on historical variation in stocks for other regions. The model is also modified in other ways in order to make it appropriate for short run (within one year) analysis.

The second contribution has to do with the issue of model validation. We take advantage of the natural experiments offered by year-to-year, weather-induced production variability to validate the resulting CGE model, by comparing historical price variation with that which is produced by the model. Our primary result is that too much of the price volatility generated by supply shocks is being absorbed elsewhere in the model. As a result, only by imposing a particularly strong stockholding response is it possible to induce the model to generate stock changes similar to those reported by the FAO. On the other hand, only if the stockholding response is turned off (by setting the response parameter, *c*, equal to zero) can the model reproduce the price volatility exhibited in FAO data for many of the model regions.. The next step is to re-examine demand, feed use, and trade elasticities, bringing the calibration to bear on these parameters as well.

The refined short-run model resulting from this exercise will have many possible uses, such as addressing questions of trade policy and price volatility in the presence of production uncertainty (e.g., Claessens and Duncan, 1993), and examining issues related to the vulnerability of low income households due to international price volatility for staple grains (Berck and Bigman, 1993). The model could also be used without uncertain production for the purpose of quantifying short run policy impacts. Finally, this work could serve as a template for conducting short run analysis of other non-perishable commodity markets where stock-holding is an important component of year-to-year adjustment.

References

Berck, P. and D. Bigman. *Food Security and Food Inventories in Developing Countries*, Wallingford: CAB International. 1993.

Burfisher, M. and E. Jones. “Regional Trade Agreements and US Agriculture,” USDA/ERS Agricultural Economics Report No. 771. 1998.

Claessens, S. and R.C. Duncan. *Managing Commodity Price Risk in Developing Countries*, Baltimore: The Johns Hopkins Press. 1993.

DeVuyst, E.A. and P.V. Preckel. “Sensitivity Analysis Revisited: A Quadrature Based Approach”, *Journal of Policy Modeling* 19(2):175-85. 1997

Dimaranan, B.V. and R.A. McDougall. *Global Trade, Assistance, and Production: The GTAP 5 Data Base*, Center for Global Trade Analysis, Purdue University. 2002.

Dixon, P.B. and M.T. Rimmer. *Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH*. Amsterdam: North Holland. 2002.

Edwards, S. “Openness, Productivity and Growth: What Do We Really know?” *Economic Journal* (108): 383-398. 1998.

FAOSTAT. *Food and Agriculture Organization Statistics Databases*, Internet site: www.fao.org. Accessed: April-May 2003.

Francois, J. F. and C.R. Shiells. “AGE Models of North American Free Trade”, ch. 1 in Francois and Shiells (eds.) *Modeling Trade Policy: Applied General Equilibrium Assessments of North American Free Trade*, New York: Cambridge University Press. 1994.

Hertel. T. W. *Global Trade Analysis: Modeling and Applications*, Cambridge: Cambridge University Press. 1997.

Hertel, T., P. Preckel, and J. Reimer. “Trade Policy, Staple Food Price Variability, and the Vulnerability of Low-Income Households,” Paper presented at the Fourth Annual Conference on Global Economic Analysis, Purdue University. 2001.

Hodrick, Robert J. and Edward C. Prescott. “Postwar U.S. Business Cycles: An Empirical Investigation,” *Journal of Money, Credit, and Banking*, 29:1 (Feb.), 1-16. 1997.

Kennedy, Peter. *A Guide to Econometrics*. Cambridge: MIT Press. 1998.

Kydland, Finn E. and Edward C. Prescott. “The Computational Experiment: An Econometric Tool,” *Journal of Economic Perspectives*, 10:1, 69-85. 1996.

Martin, W. and L.A. Winters, eds. *The Uruguay Round and the Developing Countries*, Cambridge: Cambridge University Press. 1997.

Newbery, David M.G. and Joseph E. Stiglitz. *The Theory of Commodity Price Stabilization*, Oxford: Oxford University Press. 1981.

OECD (Organization of Economic Cooperation and Development). *Agricultural Policies in OECD Countries: A Positive Agenda for Reform*. OECD, Paris, France. 2002.

Tyers, R. and K. Anderson. *Disarray in World Food Markets*, Cambridge: Cambridge University Press. 1992.

Vanzetti, D. *Global Stocks, Price Stability and Food Security*, Report No. 95, Danish Institute for Agricultural and Fisheries Economics, Copenhagen. 1998.

Williams, J.C. and B. D.Wright. *Storage and Commodity Markets*, Cambridge: Cambridge University Press. 1991.

Figure 1. Estimation of stockholding model for U.S. wheat, 1966-1995

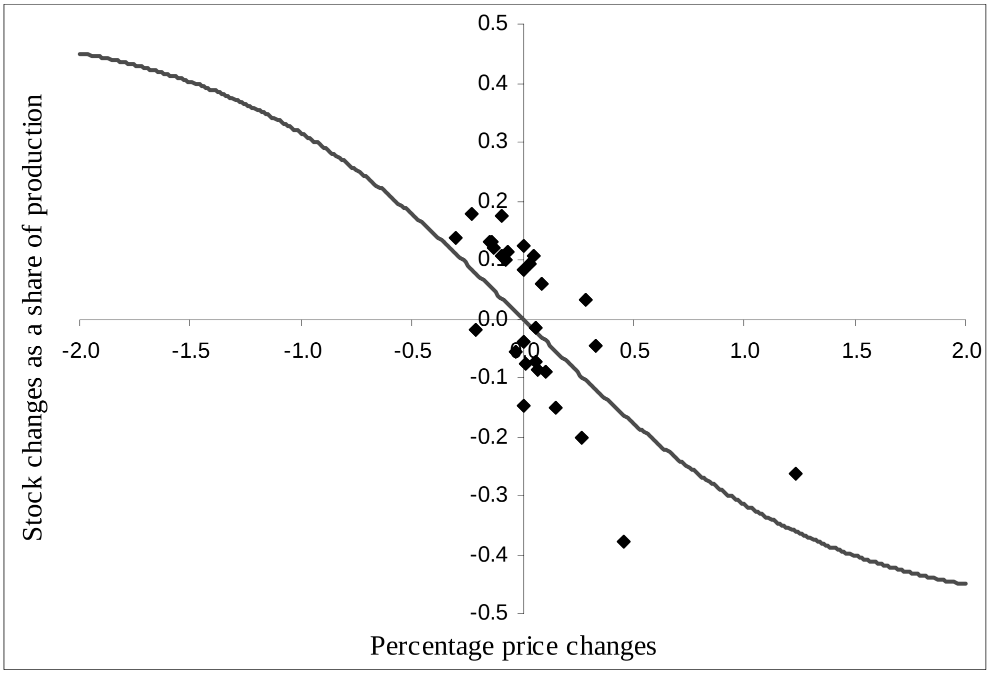

Figure 2. U.S. wheat production and trend over time

Table 1. Standard deviation of stock changes normalized on production

Region	Actual, observed std. deviation of stock changes*	Std. deviation associated with ex-post calibration**	Calibrated value of *c*
North America	0.132	0.131	-9.8
Latin America	0.039	0.038	-3.4
Western Europe	0.058	0.058	-5.9
Eastern Europe	0.104	0.103	-4.0
Former USSR	0.141	0.140	-48.0
High Income East Asia	0.105	0.082	-65.0
South East Asia	0.038	0.036	-15.0
South Asia	0.087	0.052	-90.0
China	0.015	0.014	-7.3
Middle East North Africa	0.073	0.074	-3.1
Africa Sub Sahara	0.052	0.052	-2.2
Oceania	0.325	0.311	-55.0

* Calculated with data from FAOSTAT (2003).
** Based on authors’ simulations.

Table 2. Standard deviation of wheat price changes

Regions	**Actual, observed std. deviation of price changes***	**Std. deviation associated with ex-post calibration****	**Std. deviation when $c = 0$ (max variation)**
North America (U.S. and Canada; maize, soybean, wheat)	19 - 32	5.2	33.2
Latin America (Costa Rica, Mexico, Argentina, Brazil; maize, rice, soybean, wheat)	30 - 45	22.9	42.3
Western Europe (France and Spain ; maize, soybean, wheat)	6 - 17	14.5	30.7
Eastern Europe (Albania, Bulgaria, Hungary, Poland, Romania; maize, wheat)	11 - 83	12.2	32.2
Former USSR (Maize, soybean, wheat)	10 - 18	1.3	35.0
High Income East Asia (Japan and South Korea; rice)	7 - 12	1.2	38.5
South East Asia (Indonesia, Malaysia, Thailand; rice)	6 - 22	3.8	19.2
South Asia (Bangladesh, India, and Pakistan; rice)	14 - 30	4.4	11.0
China (Maize, soybean, rice, wheat)	8 - 12	7.6	17.3
Middle East North Africa (Algeria, Egypt, Israel, Jordan, Morocco, Saudi Arabia; maize, wheat)	11 - 50	23.0	41.5
Africa Sub Sahara (Cameroon, Mozambique, Nigeria, Zimbabwe, Zambia; maize, wheat)	20 - 48	45.8	64.2
Oceania (Australia and New Zealand ; maize and wheat)	14 - 24	1.4	27.7

* Calculated with data from FAOSTAT (2003).

** Based on authors' simulations. The same *c* values as in Table 1 are used.

Appendix Table 1. Sectoral aggregation

Original GTAP sectors	Aggregated 15 sectors
Paddy rice	Grains
Wheat	Grains
Cereal grains nec	Grains
Vegetables, fruit, nuts	OtherAg
Oil seeds	OtherAg
Sugar cane, sugar beet	OtherAg
Plant-based fibers	OtherAg
Crops nec	OtherAg
Cattle,sheep,goats,horses	Livestock
Animal products nec	Livestock
Raw milk	Livestock
Wool, silk-worm cocoons	Livestock
Forestry	Forestry
Fishing	Livestock
Coal; Oil; Gas	Mining
Minerals nec	Mining
Meat: cattle,sheep,goats,horse	ProcLstk
Meat products nec	ProcLstk
Vegetable oils and fats	ProcFood
Dairy products	ProcLstk
Processed rice	ProcRice
Sugar	ProcFood
Food products nec	ProcFood
Beverages and tobacco products	BevTobac
Textiles; Wearing apparel	Apparel
Leather products	NonDur
Wood products	NonDur
Paper products, publishing	NonDur
Petroleum, coal products	NonDur
Chemical,rubber,plastic prods	NonDur
Mineral products nec	NonDur
Ferrous metals	Durables
Metals nec	Durables
Metal products	Durables
Motor vehicles and parts	Durables
Transport equipment nec	NonDur
Electronic equipment	Durables
Machinery and equipment nec	NonDur
Manufactures nec	NonDur
Electricity	HousUtil
Gas manufacture, distribution	HousUtil
Water	HousUtil
Construction	HousUtil
Trade	TradeTrans
Transport nec; Sea transport; Air	TradeTrans
Communication	TradeTrans
Financial services nec	OthService
Insurance	OthService
Business services nec	OthService
Recreation and other services	OthService
PubAdmin/Defence/Health/Educat	OthService
Dwellings	HousUtil

Appendix Table 2. Definition of staple grains*

FAO Cereals, Total (No. 1717)	GTAP database equivalent
Wheat	Wheat
Rice, Paddy	Paddy rice
Barley	Cereal grains
Maize	Cereal grains
Pop Corn	Cereal grains
Rye	Cereal grains
Oats	Cereal grains
Millet	Cereal grains
Sorghum	Cereal grains
Buckwheat	Cereal grains
Quinoa	Cereal grains
Fonio	Cereal grains
Triticale	Cereal grains
Canary Seed	Cereal grains
Mixed Grain	Cereal grains
Cereals nes	Cereal grains

* All of these categories are included into the “staple grains” category of our analysis.

Appendix Table 3. Regional aggregation

Original GTAP regions	Aggregated 13 regions
Botswana	Africa Sub Sahara
Rest of SACU (Namibia,RSA)	Africa Sub Sahara
Malawi	Africa Sub Sahara
Mozambique	Africa Sub Sahara
Tanzania	Africa Sub Sahara
Zambia	Africa Sub Sahara
Zimbabwe	Africa Sub Sahara
Other Southern Africa	Africa Sub Sahara
Uganda	Africa Sub Sahara
China	China
Hungary	Eastern Europe
Poland	Eastern Europe
Rest of Central European Assoc	Eastern Europe
Hong Kong	High Income East Asia
Japan	High Income East Asia
Korea	High Income East Asia
Taiwan	High Income East Asia
Singapore	High Income East Asia
Mexico	Latin America & Caribbean
Central America, Caribbean	Latin America & Caribbean
Colombia	Latin America & Caribbean
Peru	Latin America & Caribbean
Venezuela	Latin America & Caribbean
Rest of Andean Pact	Latin America & Caribbean
Argentina	Latin America & Caribbean
Brazil	Latin America & Caribbean

Appendix Table 3 (continued)

Original GTAP regions	Aggregated 13 regions
Chile	Latin America & Caribbean
Uruguay	Latin America & Caribbean
Rest of South America	Latin America & Caribbean
Turkey	Middle East North Africa
Rest of Middle East	Middle East North Africa
Morocco	Middle East North Africa
Rest of North Africa	Middle East North Africa
Canada	North America Developed
United States	North America Developed
Australia	Oceania Developed
New Zealand	Oceania Developed
Rest of South Asia	ROW
Rest of EFTA	ROW
Rest of Sub-Saharan Africa	ROW
Rest of World	ROW
Bangladesh	South Asia
India	South Asia
Sri Lanka	South Asia
Indonesia	South East Asia
Malaysia	South East Asia
Philippines	South East Asia
Thailand	South East Asia
Vietnam	South East Asia
Former Soviet Union	Former Soviet Union
Austria	Western Europe
Belgium	Western Europe
Denmark	Western Europe
Finland	Western Europe
France	Western Europe
Germany	Western Europe
United Kingdom	Western Europe
Greece	Western Europe
Ireland	Western Europe
Italy	Western Europe
Luxembourg	Western Europe
Netherlands	Western Europe
Portugal	Western Europe
Spain	Western Europe
Sweden	Western Europe
Switzerland	Western Europe