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Storage–trade interactions under uncertainty Implications for food security

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Abstract

The recent trend towards a more market-oriented global economy has reduced public support to commodity programs and led to a decline in buffer stocks of food grains in several cereal-exporting countries. Countries have to look for alternative means to stabilize prices and consumption particularly when carrying buffer stocks is expensive and self-sufficiency is economically inefficient. In today's market place, any country has the option of consuming food that is produced domestically or imported. This paper shows that trade and buffer stocks are two principal means to reconcile the conflicting realities of *unstable* harvests and *stable* consumption needs. © 2001 Society for Policy Modeling. Published by Elsevier Science Inc.

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1. Introduction

This paper provides an empirical assessment of domestic and international linkages in storage and trade of under stochastic production conditions in an

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interdependent and competitive global market place. Using a dynamic rational expectations model of the world wheat market (WWM), we show that storage and trade respond differently to domestic and foreign production uncertainties. Results indicate that an increase in world production uncertainty would lead to an increase in US buffer stocks and a decrease in US exports. Results point to trade as an important source of food security for all countries in the future.

The purpose of storage in a dynamic, stochastic world is to absorb production shocks and move grains from a surplus year to a deficit year and, thus, maintain market stability. The advantages of buffer stock operations to bring market stability have been widely noted (Bigman & Reutlinger, 1979; Gardner, 1979; Gustafson, 1958; Jha & Srinivasan, 1997; Just, Lutz, Schmitz, & Turnovsky, 1977; Reutlinger, 1976; Sarris & Freebairn, 1983; Sharples & Martinez, 1993; Williams & Wright, 1991). When a country is open to trade, the potential market instabilities caused by domestic production fluctuations can also be offset through trade. Trade, however, can also transmit fluctuations in supply in other countries to the domestic market. Consequently, storage for a given country will differ substantially in the presence of trade. Similarly, equilibrium trade will be different in the presence of storage.

The recent trend towards a more market-oriented global economy has reduced public support to commodity programs and led to a decline in buffer stocks of food grains in several cereal-exporting countries. In 1995, global stocks of food grains were reduced to 17% of historical consumption levels, a level considered to be "dangerously low" by FAO (FAO, 1995). Lower stocks could increase the possibility of significant price spikes in years when global production falls substantially below trend (Hazell, 1993, p. 41).

Self-sufficiency may also be economically inefficient because it may divert resources away from a country's comparative advantage (Anderson & Hazell, 1994, p. 321). Several studies have indicated that food supplies can be stabilized more cheaply by trading in world markets than by domestic storage (Tweeten, 1996; Valdes, 1981). A more open trade regime will promote international price stability as production at the aggregate or global level is steadier than at the regional or national level. Trade and buffer stocks are two principal means to reconcile the conflicting realities of *unstable* harvests and *stable* consumption needs. In this article, we examine the effects of random production fluctuations on equilibrium functions of storage and trade. We also examine the response of storage and trade to price (supply and demand) uncertainties in the rest-of-the-world (RW) market.

2. The market model

This section presents a "three-region" world wheat market consisting of two net exporters, the US and the European Union (EU), and one net importer, the combined rest-of-the-world (RW). Trade is assumed to occur between exporters and the importer, with no trade between the two exporters. The model is presented in two parts: the model for exporters and the model for RW.

2.1. Exporters

The following structural model outlines market characteristics of the two exporting entities, the US and the EU. The framework of supply, demand, and arbitrage conditions are similar between the US and the EU.

2.1.1. Material balance

The available supply in country i in period t (A_t^i) is composed of current production (Q_t^i) plus the carryover from the last period (S_{t-1}^i). The country must allocate A_t^i among consumption (C_t^i), storage (S_t^i), and exports (X_t^i). The resulting intertemporal equilibrium is summarized in the following material balance equation (Eq. (1)):

$$Q_t^i + S_{t-1}^i = A_t^i = C_t^i + S_t^i + X_t^i, \qquad \forall\ i = \text{US, EU}. \tag{1}$$

The state variable A_t^i reflects the state of the economy, which summarizes all the relevant past and current information. This specification assumes no losses in storage and no qualitative differences between the stored commodity and the freshly harvested commodity.

2.1.2. Consumption demand

Current consumption, feed, and seed use in country i (C_t^i) is a downward sloping function of current market price (P_{t}^i) (Eq. (2)):

$$C_t^i = \alpha^i (P_t^i)^{\beta^i}, \qquad \forall\ i = \text{US, EU} \tag{2}$$

where $\alpha^i > 0$ is the constant term and $\beta^i < 0$ is the price elasticity of demand. Consumption of wheat in the US and the EU is assumed to be nonstochastic and consumers' income is assumed to be constant in both regions.

2.1.3. Production

The current production in country i (Q_t^i) equals the acreage planted in the preceding year (L_{t-1}^i) times a random yield per acre (Y_t^i) (Eq. (3)):

$$Q_t^i = L_{t-1}^i Y_t^i, \qquad \forall\ i = \text{US, EU}. \tag{3}$$

The acreage planted by rational producers in country i (L_t^i) depends on the price expected to prevail at harvest time ($E_t P_{t+1}^i$) (Eq. (4)):

$$L_t^i = a^i [E_t P_{t+1}^i]^{\eta^i}, \qquad \forall\ i = \text{US, EU}, \tag{4}$$

where $a^i > 0$ is the constant term and $\eta^i > 0$ is the price elasticity of supply in country i. Yield is assumed to be random with a known probability distribution.

The yield distribution is independently and identically distributed through time and across space.

2.1.4. Storage

Storage is by expected profit maximizing arbitrageurs. Competition among the risk-neutral stockholders eliminates speculative profits, yielding the following intertemporal arbitrage condition:

$$P_t^i + k^i(S_t^i) = \delta^i E_t(P_{t+1}^i), \qquad \forall\ i = \text{US, EU} \tag{5}$$

where $\delta^i=(1+r^i)^{-1}$ is the annual discount factor when the annual interest rate is r^i, $E_t(P_{t+1}^i)$ is the expectation of P_{t+1}^i, conditional on the information available in period t, and $k^i(S_t^i)$ is the marginal cost of storage. The intertemporal arbitrage condition (Eq. (5)) implies that, at the margin, the expected gain from holding an additional unit of stock is equal to the cost of holding it. Economic profit gained from stockholding is presumed to cause individuals and firms to pursue additional storage. This decreases expected gains and increases marginal costs, bringing equilibrium between marginal benefits and marginal costs.

The discount rate represents the opportunity cost of funds tied up in holding stocks. Storage costs, on the other hand, include cost of handling, the rental value of storage space, and insurance against theft or damage. The marginal cost of storage is specified as an increasing function of amount stored (Eq. (6)):

$$k^i(S_t^i) = k_1^i + k_2^i \ln(S_t^i), \qquad \forall\ i = \text{US, EU} \tag{6}$$

where k_1 and k_2 are parameters. This specification of the marginal cost function allows for a convenience yield to storage, which represents the amount commodity processors are willing to pay to have a stable supply (Brennan, 1958; Kaldor, 1939; Working, 1948, 1949).

2.1.5. International trade

International trade is undertaken by private traders who exploit spatial arbitrage profit opportunities. Competition among such traders eliminates excess arbitrage profits. Net exports from country i (X_t^i) to RW are a function of market prices in the regions, per unit shipping costs (τ^i), and the per unit export subsidy provided by the government (g^i). Trade is subject to the following spatial arbitrage condition:

$$\begin{aligned} &P_t^i + \tau^i - g^i = P_t^{\text{RW}}, \quad X_t^i > 0 \\ &P_t^i + \tau^i + g^i \geq P_t^{\text{RW}}, \quad X_t^i = 0, \qquad \forall\ i = \text{US, EU.} \end{aligned} \tag{7}$$

Eq. (7) says that, if the buying cost plus shipping cost less government subsidy exceeds the selling price in RW, then no trade will take place. This also implies that trade takes place in one direction only — from the US or the EU to RW.

2.2. Rest of the world

RW is assumed to be a large consumer with no significant wheat stock holdings. It is assumed to represent the world wheat import market where the US and the EU compete to sell wheat. RW is represented by a stochastic net demand function.

2.2.1. Consumption demand

Current import consumption or total consumption less production in RW (C_t^{RW}) is a function of current market price (P_t^{RW}):

$$C_t^{RW} = \alpha^{RW}(P_t^{RW})^{\beta^{RW}} + u_t^{RW}, \tag{8}$$

where the random variable u_t^{RW} is assumed to be normally distributed with mean zero and variance σ^2. The random shocks are independently and identically distributed. Expression (8) is a net demand function. The random component, therefore, accounts for variation coming from both the supply and the demand side.

2.2.2. Market clearing condition

The model is closed by assuming the following market clearing condition:

$$X_t^{US} + X_t^{EU} = C_t^{RW}, \tag{9}$$

where the sum of exports from the US and the EU is equal to net consumption in RW.

2.3. Model parameterization

The parameters used in the study are representative of the US, the EU, and RW wheat sectors. Econometric studies indicate that the price elasticity of domestic demand for wheat in the two exporting regions is approximately −0.2 (Bailey, 1989; Gardner, 1979; Reutlinger, 1976; Rojko, Reggier, O'Brein, Coffing, & Bailey, 1978; Sarris & Freebairn, 1983; Sullivan, Wainio & Roningen, 1989; Tyers & Anderson, 1986). The reported price elasticities of demand for major importers range from −0.10 to −0.40 (Sullivan et al., 1989). For the present study, the price elasticity of demand for RW is calculated to be −0.31, which is a weighted average of major importers. Wheat supply elasticity estimates for the US and the EU reported in the literature vary widely. Sarris and Freebairn estimated a short-run wheat supply elasticity of 0.2 for the US and 0.35 for the EU, while OECD (1986) estimates were 0.5 and 0.46, respectively, for the US and the EU. In the present study, a supply elasticity of 0.3 is assumed for both the US and the EU.

The interest or discount rate represents the opportunity cost of holding stocks. The real rate of return on private assets in the US, about 10% (see Malkiel, 1990), adjusted for a tax rate of 30% (see Gardner, 1979, p. 126) gives the real rate of

Table 1
Competitive equilibrium storage and trade of US wheat under alternative production variabilities in the world[a,b]

	CV of yield = 0%		CV of yield = 10%		CV of yield = 15%	
Supply[c] (million bushels)	Storage (million bushels)	Exports (million bushels)	Storage (million bushels)	Exports (million bushels)	Storage (million bushels)	Exports (million bushels)
1800	0.00	653.15	0.00	652.87	0.80	649.09
2000	1.70	806.04	3.61	804.98	4.08	804.82
2200	15.53	953.77	23.78	949.20	31.14	941.85
2400	54.19	1087.71	67.70	1080.24	70.90	1079.60
2600	113.58	1210.13	129.35	1201.42	134.40	1199.62
2800	181.41	1327.85	197.03	1319.24	225.72	1288.17
3000	248.64	1445.90	263.12	1437.94	312.96	1378.77
3200	320.97	1561.10	333.88	1554.01	379.96	1504.76

[a] Coefficient of variation (CV) of production in the US and the EU are equal and vary simultaneously in both the regions; CV of consumption in RW is held constant at 10%.

[b] The results for the EU are similar to those of the US.

[c] Supply in the EU is held constant at 2.4 billion bushels.

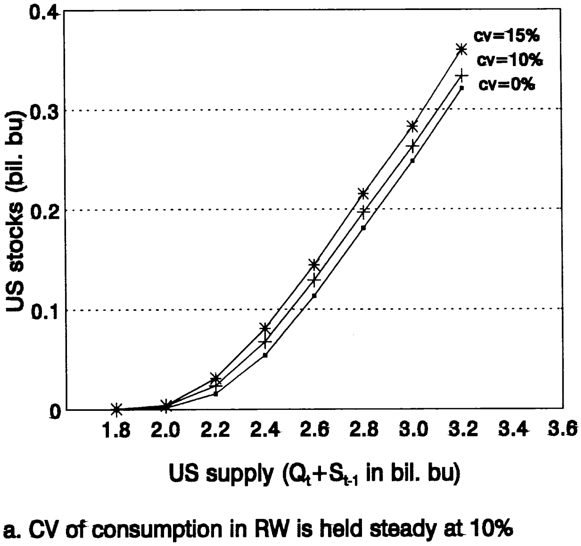

Fig. 1. Equilibrium storage rules for US wheat under varying production uncertainties in the world.

interest of 7% used in both regions. Storage cost function parameters are chosen such that the non-interest cost of storage lies near 10% of the price during normal production. International shipping costs are assumed to be \$0.50 per bushel, which is approximately equal to 12.5% of the current price of \$4.00 per bushel (FAO predicts average shipping costs to be 10% to 15% of the price). Similar parameter estimates are assumed in the EU.

The random yields both in the US and the EU are assumed to follow a log-normal distribution with an estimated mean of 40 and 66 bushels per acre, respectively, and an identical coefficient of variation (CV) of 10%. This compares with actual CVs of yield for the period 1980–1993 of 8.5% and 12% for the US and the EU respectively (see also Tweeten, 1994; Ray, Slinsky, Pendergrass, & White, 1994). The random shock variable u_t in the RW demand function is assumed to be normally distributed with mean zero and standard deviation 0.1.

2.4. Dynamic rational expectations equilibria

The Chebychev orthogonal polynomial projection and collocation method is used to solve for the competitive equilibrium conditions (Judd, 1991, 1992; Makki, Tweeten, & Miranda, 1996; Miranda & Glauber, 1993, 1995; Williams & Wright, 1991; Wright & Williams, 1982, 1984). Producers and stockholders, whose current actions are based on future prices, are assumed to be rational in the sense of Muth (1961). The expected price functions, which generally lack known closed form expressions, are approximated using a sequence of Chebychev polynomials. The integral of conditional expectations, which also lack known

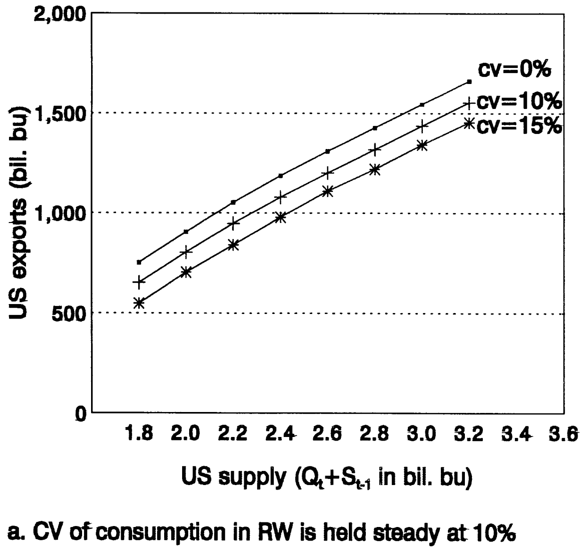

Fig. 2. Equilibrium export rules for US wheat under varying production uncertainties in the world.

closed-form expressions, are computed using Gaussian quadrature. The equilibrium functions are computed by successive approximation and the steady state mean and CV are estimated from samples of 100 000 observations generated through Monte Carlo simulations. For any given regime, the model is simulated by repeatedly drawing random yields in the US and the EU and random shocks for the RW demand from the respective assumed distributions. For details see Makki (1995) or Miranda and Glauber (1995).

3. Results

Food grain production varies greatly from year to year due to fluctuations in acreage and yield. Production variation due to fluctuations in acreage is, however, more predictable and, hence, causes less uncertainty compared to production variation caused by fluctuations in yield. The main emphasis of this paper, therefore, is on the uncertainty introduced by random fluctuations in yield per acre. Variation in yield is primarily caused by uncertain weather. In the present study, future yields cannot be predicted with precision but are subject to probability distributions with known mean and variance. The underlying uncertainty in the weather and other natural factors (e.g., pest and diseases) are expressed by the CV of yield per acre.

Table 1 presents equilibrium storage and trade rules for the US under varying production uncertainties in the US and in the EU. Results indicate that a higher CV of production increases stockholdings and decreases exports. The

Table 2
Steady-state mean and CV of price, consumption, storage, exports, acreage, and production of wheat under different production variabilities in the world[a]

	CV of yield = 0%		CV of yield = 10%		CV of yield = 15%	
Variables	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
US						
Price ($/bushel)	3.39	0.45	3.38	19.57	3.33	22.36
Consumption (million bushels)	1256.66	0.00	1256.76	3.94	1261.69	3.82
Storage (million bushels)	51.17	6.18	148.93	80.43	167.05	82.20
Exports (million bushels)	1093.10	0.29	1177.32	17.50	1101.51	26.02
Acreage (mil. ac.)	58.74	0.00	60.50	1.01	58.52	7.64
Production (million bushels)	2349.76	0.00	2437.91	12.15	2371.23	18.03
EU						
Price ($/bushel)	3.39	0.44	3.38	19.57	3.31	23.36
Consumption (million bushels)	1301.65	0.00	1301.76	3.40	1310.35	6.04
Storage (million bushels)	51.17	6.18	148.93	80.43	165.28	89.20
Exports (million bushels)	1019.45	0.31	1046.80	19.37	1022.11	26.72
Acreage (million acres)	38.69	0.00	38.89	1.00	38.72	6.50
Production (million bushels)	2321.10	0.00	2350.99	12.20	2340.70	12.73
RW						
Price ($/bushel)	3.89	0.18	3.88	17.05	3.84	20.13
Consumption (million bushels)	2119.34	0.55	2224.13	4.89	2123.63	5.62

[a] CV of production are equal and change simultaneously in the US and the EU. The CV of consumption in RW is held constant at 10%.

competitive storage rule for the US, for example, says that for a beginning supply of 2.6 billion bushels, the equilibrium storage would be 114 million bushels when the CV of production is 0%, 129 million bushels when the CV is 10%, and 134 million bushels when the CV is 15%. For the same initial supply, the equilibrium storage increased by 16 million bushels, or 14%, when the production variance increased from zero to 10%. In contrast, exports fell by 9 million bushels for similar increases in the CV of production. This implies that the increase in stockholdings was partly supplied by reduced exports. With higher production variability, agents find it profitable to hold more stocks instead of shipping to RW.

Fig. 1 plots the equilibrium storage generated from simulating the model for CV=0%, 10%, and 15%. Higher future uncertainty induces rational private agents to store more. As a result, the equilibrium storage rule shifts upwards when the coefficient of variation of production increases. Fig. 2 displays equilibrium trade rules for the US for alternative production variabilities in the world. Equilibrium trade rules shift in opposite direction to equilibrium storage rules in response to higher production variability in the world. The figure indicates that US exports decrease in response to increases in the CV of production partly to free supplies for use as buffer stocks in the domestic market.

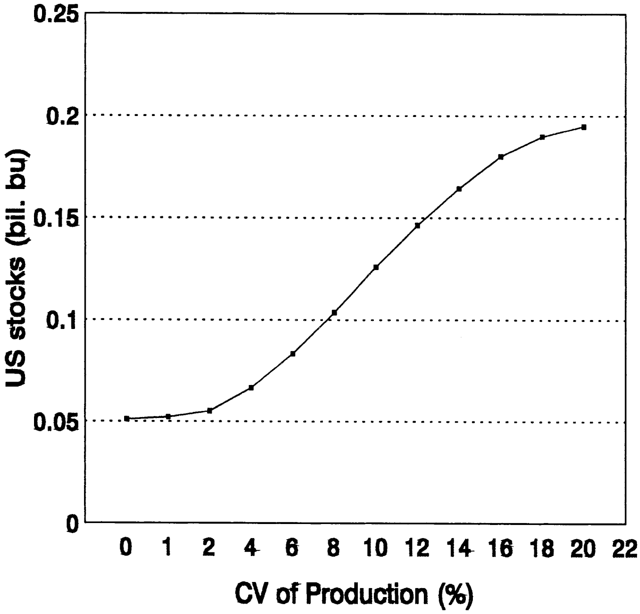

Fig. 3. Predicted effect of world production uncertainty on US stocks.

These results suggest that storage and trade are responsive to uncertainties in production. They substitute for each other differently depending on domestic and foreign supplies and the degree of production uncertainty.

The greater the variability in expected production, the larger is the steady-state mean storage (Table 2 and Fig. 3). For example, mean storage increased from 51 million bushels under certainty equivalence (CV=0%) to 149 million bushels under a CV of production of 10%, and to 167 million bushels under a CV of 15%. (Pipeline stocks, approximately 250 million bushels in the case of the US, must be added to these speculative stocks to arrive at total expected carryout in an efficient market.) The CV of storage increased from 6% to 80% when the CV of production increased from 0% to 10%. The CV of US exports also increased (Table 2). In general, exports are less responsive than storage to changes in the CV of production.

Mean prices remained unchanged in all regions, but became more volatile when the CV of production increased. The CV of price increased from less than 1% to 20% in the US and in the EU, and to 17% in RW. The CV of consumption also increased in all regions (Table 2).

3.1. Effects of locational uncertainties

We also examine the effects of having a disproportionate share of the total variance in one region, holding the total variance constant. To carry out the

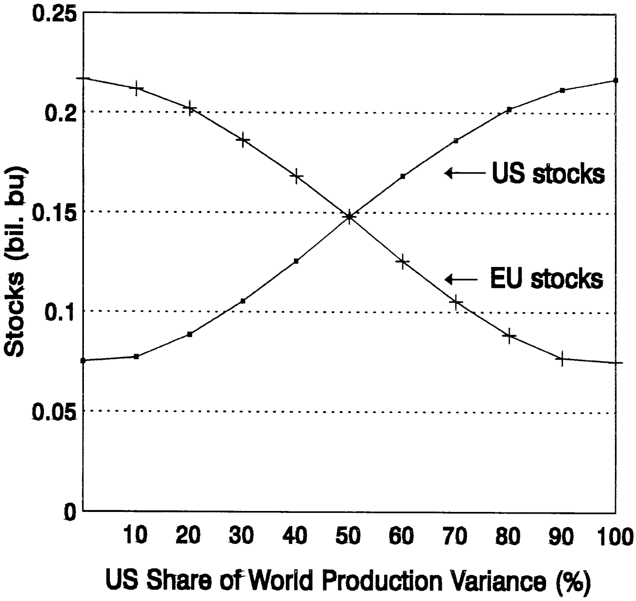

Fig. 4. Effects of locational uncertainties on US and EU stocks.

experiment, the sum of the production CV in the two regions is held constant at 0.2, while the share of the US is increased from 0% to 100%. For example, when the share of the US production variance is 40% of the total world production variance, the CV would be 0.08 for the US and 0.12 for the EU. A domestic share of 60%, on the other hand, means a CV of 0.12 for the US and 0.08 for the EU.

Fig. 4 illustrates the steady-state mean storage as a function of domestic share of the total production variance. The figure suggests that more storage takes place in the country with more uncertainties in production. Mean storage increases steadily as the CV of production increases. The storage level in the EU falls when its share of production uncertainty falls.

Table 3 illustrates how increases in interest rates in one country, for example, affect equilibrium storage and trade in all regions. Results indicate that buffer stocks in the US decrease by 31%, while stocks in the EU increase by 12% when the interest rate in the US increase from 7% to 10%, holding the interest rate in the EU steady at 7%. Results suggest that for every bushel decrease in the US stocks, the EU will increase its stockholdings by 0.4 bushels. Grain stocks in the EU increase to compensate for decrease in US stocks. The impact of higher interest rates on trade is likely to be small.

In conclusion, the study shows that an efficient market responds to both intertemporal and spatial arbitrage opportunities. In an integrated world economy an increase in the production uncertainty is matched by higher buffer stocks

Table 3
Impact of higher interest rates on world wheat market[a,b]

	Interest rates					
	8%		9%		10%	
Variables	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
US						
Price ($/bushel)	3.37	19.93	3.38	20.25	3.38	20.52
Consumption (million bushels)	1256.88	3.45	1256.99	3.50	1257.09	3.55
Storage (million bushels)	132.18	82.39	117.00	84.26	103.27	86.07
Exports (million bushels)	1177.61	17.69	1177.87	17.91	1178.11	18.15
Acreage (million acres)	60.51	1.01	60.51	1.01	60.52	1.01
Production (million bushels)	2438.10	12.15	2438.28	12.15	2438.45	12.14
EU						
Price ($/bushel)	3.38	19.93	3.38	20.25	3.38	20.52
Consumption (million bushels)	1301.86	3.45	1301.95	3.51	1302.04	3.55
Storage (million bushels)	155.21	81.50	161.30	82.50	167.15	83.43
Exports (million bushels)	1046.78	19.31	1046.78	19.30	1047.60	19.32
Acreage (million acres)	38.90	1.01	38.90	1.01	38.90	1.01
Production (million bushels)	2351.17	12.20	2351.34	12.20	2351.51	12.19
RW						
Price ($/bushel)	3.88	17.36	3.88	17.64	3.88	17.88
Consumption (million bushels)	2224.41	4.98	2224.66	5.05	2224.88	5.11

[a] Interest rate changes only in the U.S.; EU interest rate is held steady at 7%.
[b] For base period (7% interest rate and 10% CV) refer to Table 2.

supplied partly by reduced exports. These results also demonstrate the interdependence and interactions of stockholdings in the two regions.

4. Policy implications

The trend towards market orientation will reduce global buffer stocks of food grains raising concerns about food security for developed and developing countries alike. Some evidence indicates that world food production uncertainty is increasing over time (Hazell, 1993, p. 41; Tweeten, 1994). Storage and trade are alternative means to smooth domestic prices and consumption in the face of unstable domestic and foreign production. Our findings indicate that in an efficient global market rational agents store more and export less when production uncertainty increases and vice versa. Results also indicate that the country with higher share of production uncertainty stores more and exports less and at the same time the country with lower share of production uncertainty store less and exports more.

In today's market place, any country has the option of consuming food that is produced domestically or imported. Trade is an important food instability buffer and agent for food security. Indeed, for developing countries, trade is the buffer stock of choice; they often carry little buffer stocks and carrying food stocks is expensive. However, a country needs within-country storage to last until imports arrive when local production falls short. Trade and buffer stocks are, therefore, two principal means towards greater food security.

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