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Storage and the Volatility of Agricultural Prices: A Model of Endogenous Fluctuations[1]

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Abstract

Recent developments in world food markets stress the importance of identifying the sources of food price volatility. This paper develops a nonlinear Cobweb model with endogenous volatility. It supplements the famous Deaton and Laroque model based on exogenous fluctuations and storage. As with Deaton and Laroque, it leads to price series with positive skewness and autocorrelation, similar to actual commodity prices.

Keywords: Agricultural Prices; Nonlinear Cobweb Model; Endogenous Fluctuations; Storage

JEL classification: Q11, E39, D84

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Introduction

The recent crisis of agricultural commodity prices brings to the forefront the question of the volatility of food prices and the causes for such volatility. Although there is a wide consensus with respect to the negative effects of agricultural price volatility on consumers, for instance on food security and mortality (Ravallion (1997)), its sources – and therefore, the methods which can be employed to reduce it – are far from being clear.

There is perhaps one point where economists agree regarding the volatility of agricultural commodity prices: the price inelasticity of food demand does contribute to amplify price movements over time. Regarding the sources of price volatility on the supply side, there are two schools of thought.

Two Schools of Thought on the Origins of Price Fluctuations

The most commonly accepted hypothesis is the exogenous one (Cafiero and Wright (2006); Deaton and Laroque (1992), (1996)). Agricultural production is subject to weather shocks[2], which are entirely external to the market. Producers are assumed to be risk neutral and to have rational expectations, which is not realistic (Nerlove and Bessler (2001)). The other issue with this hypothesis is that with random shocks, simulated price series do not reproduce stylized facts, i.e. the skewness of the price distribution and the positive autocorrelation of first rank.

[2] Some commentators presented a drought in Australia as a major determinant of the recent price upsurge of food prices (See for example « Drought a Factor in Food Aid Shortage : UN » The Australian 13/09/2009).

The other hypothesis is an endogenous one, related to the very functioning of the market, leading sometimes to chaotic[3] phenomena. For instance, Ezekiel (1938) puts forward erroneous expectations by producers that lead to over or under supply. Ezekiel's original model leads to price movements that are periodic, converging or diverging, which again is not realistic.

There is some truth in each of these hypotheses. However, it is essential to know which hypothesis best explains observed fluctuations, because they have very different practical implications, in fact they are opposite when it comes to implications for policies to reduce the negative effects of such phenomena.

The Importance to Find Out

Under the exogenous hypothesis, it should be possible to remedy price fluctuations using methods based on the law of large numbers, such as insurance schemes, spreading risks between the "lucky" and the "unlucky", storage (which spreads risk over time) or the widening of markets (which spreads risk over space). This is because, under the law of large numbers, many independently distributed shocks, each of them being small with respect to the total, cancel out each other. For instance, the probability of a drought affecting America, Europe and Australia together is small, as well as the probability of having a long series of bad harvests in a given place. Similarly, if "bad years' are fortuitous, a long series of bad years is not credible. In this context, widening markets should stabilize prices. This is one of the reasons why the "liberalization" of agriculture was recommended by the authors who had prepared the negotiations of the World Trade Organization of the Uruguay Round, and later at Doha[4]. Likewise, in this context, large inter-annual stocks should be able to

[3] The word "chaos" is understood in its mathematical dynamics sense: it applies to the solution of a difference equation when after some time it never converges toward a stable limit while being aperiodic.
[4] The widely cited paper by Bale and Lutz (1979) is simply a demonstration of the theorem of the law of large numbers.

regulate prices. This is the reason why, for a very long time[5], public storage has been the backbone of food security policies.

Under the endogenous hypothesis, on the contrary, such strategies would be unlikely to solve the problem. The widening of markets would only synchronize, not reduce, fluctuations because the law of large numbers would no longer work. Undoubtedly, producers do not have the same expectations: their expectations can be more or less spread around the mean. There is little chance though for the mean to be at the level of rational expectations, level at which the price would be equal to the marginal cost. If there are reasons to think that the price is going to increase, all producers will expect an increase, although the exact level of the expected price will vary. However, the mean expected price will increase, which will lead later to a price decline. For a long time, many authors such as Mandelbrot (1973), or Orléan (1989) have underlined the importance of such phenomena, which might explain why shocks are correlated with each other, which goes against one of the conditions for the law of large numbers to apply and leads to distributions of macroeconomic variables that are no longer Gaussian (Zadjenweber , 2000).

When such phenomena are at play, the simple addition of variables (e.g. production) no longer regulates the sum, because each individual variable depends in fact on the same underlying mechanism. Hence, solutions based on the law of large numbers, such as widening markets, will in fact only contribute to synchronize fluctuations. In this context, one can envisage that storage, public or private, can be ill timed, hence can worsen a crisis. We will come back to this point in the model below. In such a situation, effective remedies against food price variability may include segmenting markets and developing some form of government intervention in the agricultural sector (Boussard (2006)).

[5] This has been known for at least 4,000 years, as shown by the story of Joseph in the Bible (Genesis, 41-50).

Past Studies

Despite the importance of the potential policy implications, few studies aim at providing evidence on the relevance of these two lines of explanations. Some have tried to test econometrically the endogenous versus the exogenous hypothesis (e.g., Leuthold and Wei (1998)). Unfortunately, the discriminating power of econometric tests remains questionable. An alternative line of research is to build plausible models of fluctuations in the context of one or the other hypothesis, and to see whether one of them is capable of better representing the stylized facts of the price series of interest. In this respect, and under the exogenous hypothesis, pioneering papers are those by Laroque and Deaton (1992, 1996) on storage. This is the approach we adopt in this paper by developing a simple nonlinear Cobweb model with storage that is consistent with the endogenous hypothesis.

Exploiting this idea, Laroque and Deaton - D&L thereafter- (1992, 1996) built a fascinating model which represents fairly well the actual behavior of commodity price series: uncertainty is introduced in the supply equation through Gaussian random shocks. Economic agents are assumed to be risk neutral, a constant mean supply is given once and for all, and price expectations are rational. The size of the stock is endogenous and the key variable in the model. An important additional consideration is that, with Gaussian random shocks affecting supply, the optimal stock level series is a Brownian random walk. A Brownian random walk has probability one of reaching zero over an infinite time (in practice, the probability of a zero stock is fairly high after a few periods)[6]. Therefore, price upsurges occur when the stock level is depleted to zero, thus leading to modeled price series that are quite similar to actual ones. The probability distribution of D&L's simulated series exhibit a positive skewness , which is a major characteristic of actual commodity prices series. Therefore,

[6] For that same reason, Newbery and Stiglitz (1981) are sceptical about the practical possibility of running a public storage policy at the global level.

although their model's simulated series have several limitations[7], D&L claim to have developed an almost satisfactory theory of commodity price fluctuations. Indeed, their model has been a central contribution to the theoretical understanding of the dynamics of commodity markets, as well as a decisive indicator of the validity of the "exogenous hypothesis", thus made compatible in a model with storage with skewed time series.

Yet, the question remains as to whether D&L's approach is the only one compatible with observed facts. In this paper, we show that it is possible, in the context of the endogenous hypothesis, for a chaotic model of agricultural commodity prices with storage to produce series exhibiting properties quite similar to those of D&L's series. The first section of the paper reviews chaotic models of agricultural commodity prices. The second section presents the model. The third section gives results of numerical simulations of the model, while the last section has concluding remarks.

I – Chaotic Models of Agricultural Commodity Markets

Since the beginning of the 1990s, several models of agricultural commodity prices have identified possible sources of chaotic dynamics. All involve:

i- The local instability of the supply and demand system around the equilibrium of the market because of the rigidity of food demand. The equilibrium point is then "repulsive", leading the system to go further away from equilibrium as soon as it deviates from the latter by an infinitely small quantity (as is the case for a ball in equilibrium over the sharp edge of a pencil). Chavas and Holt (1993) have indeed shown that the rigidity of food demand is a factor of chaos in agricultural commodity

[7] They conclude:" We have not been able to generate models that reproduce the autocorrelation in most of the actual commodity prices. It is possible that we have not looked sufficiently hard or cleverly, but it is also possible that high autocorrelation reflects phenomena not discussed here (...); unfortunately, it is an understanding of autocorrelation that is perhaps the most vital for the conduct of policy."

markets. They use a model of the dairy sector in the US and find that the most price inelastic demand is, the higher the Lyapunov exponent is[8], i.e. the more chaotic the dynamics of the model becomes.

ii- Another mechanism that tends to bring the system back toward the equilibrium point when the former becomes too far from the latter (like the ball of a bilboquet, which is attached to the handle with a string). This other mechanism takes different forms in the literature. Chavas and Holt (1993) use nonlinear supply and demand curves. Finkenstadt and Kuhbier (1992) present a cobweb model with combines a nonlinear demand curve and adaptive expectations. Boussard (1996) uses a linear demand curve, but uses constant or naïve expectations, and assumes that the producer is risk averse.

These models have been able to demonstrate that it is possible to get purely endogenous fluctuations when one abandons assumptions of linearity, rationality and risk neutrality that are typical of the traditional models of exogenous fluctuations. However, these models have not been studied empirically to assess if the chaotic models can reproduce the stylized facts of agricultural commodity prices, in particular their positive skewness and autocorrelation of first rank. In fact, the chaotic models that have been developed in a general context, not specifically for agriculture, generally lead to a dynamic that often exhibit negative skewness and low first order autocorrelation (Brock, Dindo and Hommes (2007); Hommes (1998); Hommes and van Eekelen (1996)). They thus lead to fluctuations that greatly differ from those of actual agricultural prices. In the context of the exogenous hypothesis, D&L (1992) were first in a similar situation with simulated series with no first order auto-correlation and perfect symmetry. It is only when storage is introduced in their model

[8] The lyapunov exponent is an index which measures the degree of instability of a series (Alligood *et al.* (1998)).

that simulated series started to exhibit asymmetry and first order autocorrelation. Might a chaotic model with storage be able to reproduce the stylized characteristics of agricultural commodity prices? This is what we try to do below, and what makes this paper original.

II. A New Model including Storage

The agricultural commodity under consideration is harvested annually, and consumed during two seasons. The production decision is made by a representative farmer/producer in season 1 ("autumn"), while the storage decision is made by a representative storage firm during both seasons. The quantity planted by the farmer in autumn is available for sale to the storage firm during season 2 ("summer"). The market is segmented into a local market where the farmer sells the commodity to the storage firm and a central market where the storage firm sells the commodity to consumers. This scenario is especially relevant for developing economies where production and consumption are geographically dispersed and where transport infrastructure is limited. It is also plausible for some regions of developed countries (Bobenrieth, Bobenrieth and Wright (2006)).

Let $p^c_{t,i}$ and $q^c_{t,i}$ be respectively the price and quantity of the commodity on the central market during season *i* of year *t*. The production decision is taken in autumn (season 1) with a linear marginal cost as follows;,

$$p^c_{t,1} = a_i q^c_{t,1} + b_i \quad (1)$$

where *a* and *b* are constant scalar coefficients, with $a \geq 0, b \geq 0.$ During both seasons, the price is determined by the following nonlinear inverse demand function

$$p^c_{t,i} = \beta_i (q^c_{t,i})^{-\alpha_i} \quad (2)$$

where α_i, β_i are constant scalar coefficients, with $\alpha_i \geq 0, \beta_i > 0$. In autumn, no exchange takes place on the local market between the farmer and the storage firm. In summer, production is sold by farmers to storage firms at local market price $p_{t,2}^{l}$, which is assumed to be a linear function of the central market price $p_{t,2}^{c}$:

$$p_{t,2}^{l} = p_{t,2}^{c} - T \tag{3}$$

with *T>0* standing for transportation and handling costs.

In autumn, two decisions are made: the production level by the farmer (*f*) and the storage level by the storage firm or marketer (*m*). Both the farmer and the storage firm are assumed to be risk averse. In choosing the quantity $h_{t,1}$ to be produced, the farmer maximizes $W_{f,t,2}^{*}$, the expected utility from income next summer (with the * super script standing for expectation). Since expected income is $p_{t,2}^{l*}h_{t,1}$, the present value of the certainty equivalent[9] is:

$$W_{f,t,2}^{*} = \frac{p_{t,2}^{l*}h_{t,1}}{1+r} - \frac{A_f Var^{*}(p_{t,2}^{l*}h_{t,1})}{1+r} \tag{4}$$

with A_f the absolute risk aversion coefficient of the farmer[10], *r* the interest rate, and *Var* the variance operator. At equilibrium, the marginal benefit of production $\frac{dW_{f,t,2}^{*}}{dh_{t,1}}$ equals the marginal cost of production $p_{t,1}$, as given by (1) and (3) above, which yields the supply function:

[9] The certainty equivalent, here, is assumed to be a linear combination of mean and variance, following the old Markowitz (1970) model. Much more sophisticated and satisfactory models of rational behavior in face of risk have been published since. The mean/variance approach, nevertheless, has the merit of simplicity, while keeping relevance in non extreme situations. At the same time, given that we attempt to reproduce stylized facts rather than make empirical estimations, a better level of accuracy is probably not needed.

[10] It is important to note – as one reviewer noted- that the use of a constant coefficient of risk aversion is not realistic since it varies with wealth (Bar-Shira, Just and Zilbernan (1997)), and that wealth varies in time (especially across seasons). Further research might remedy this deficiency of the model.

$$h_{t,1} = \frac{\frac{p^{l*}_{t,2}}{1+r} - b + T}{a + \frac{2A_f Var^*(p^{l*}_{t,2})}{1+r}} \quad (5)$$

Price expectations are adaptive with a lag of two to account for market seasonality:

$$p^{l*}_{t,2} = p^{l*}_{t-2,2} - \lambda_f (p^{l*}_{t-2,2} - p^{l}_{t-2,2}) \quad (6)$$

with $0 \le \lambda_f \le 1$. Finally, $Var^*(p^{l*}_{t,2})$, is estimated through a naive expectation scheme, as in Boussard (1996):

$$Var^*(p^{l*}_{t,2}) = (p^{l}_{t-1,2} - p^{l}_{t-2,2})^2 \quad (7)$$

On the other side, the storage firm decides how much to store to maximize the expected utility of income $W^*_{m,t,2}$, which is given by the present value of the certainty equivalent[11] of the revenue net of the storage cost and the opportunity cost of the quantity stored:

$$W^*_{m,t,2} = \frac{p^{c*}_{t,2}(s_{t-1,2} - s_{t,1}) - A_m Var^*(p^{c*}_{t,2}(s_{t-1,2} - s_{t,1}))}{1+r} - s_{t,1}\delta - p^{c}_{t,1}s_{t,1} \quad (8)$$

subject to $0 \le s_{t,1} \le s_{t-1,2}$, where A_m is the absolute risk aversion coefficient of the storage firm, and δ is the cost of storage.

Both storage firms and farmers have the same price and variance expectation schemes[12]. Thus, in (8), in order to get the storage firm's utility, we substitute $p^{c*}_{t,2}$ with $p^{c*}_{t-2,2} - \lambda_m(p^{c*}_{t-2,2} - p^{c}_{t-2,2})$, $Var^*(p^{c*}_{t,2})$ with $(p^{c}_{t-1,2} - p^{c}_{t-2,2})^2$, and $p^{c}_{t,1}$ with $\beta_1(s_{t-1,2} - s_{t,1})^{-\alpha_i}$ from (2):

$$W^*_{m,t,2} = \frac{(p^{c*}_{t-2,2} - \lambda_m(p^{c*}_{t-2,2} - p^c_{t-2,2}))(s_{t-1,2} - s_{t,1}) - A_m(s_{t-1,2} - s_{t,1})^2(p^c_{t-1,2} - p^c_{t-2,2})^2}{1+r} - s_{t,1}\delta - (\beta_1(s_{t-1,2} - s_{t,1})^{-\alpha_1})s_{t,1} \quad (9)$$

$s_{t,1}$ is determined by setting $\frac{dW^*_{m,t,2}}{ds_{t,1}} = 0.$ Once $s_{t,1}$ is found, then the prices on the central and local markets are given by $p^c{}_{t,1} = \beta_1(s_{t-1,2} - s_{t,1})^{-\alpha_1}$ and by equation (3) respectively.

During the summer, the storage firm determines the quantity to be stored $s_{t,2}$ by maximizing:

$$W^*_{m,t+1,1} = \frac{p^{c*}_{t+1,1}(h_{t,1} + s_{t,1} - s_{t,2}) - A_m Var^*(p^{c*}_{t+1,1}(h_{t,1} + s_{t,1} - s_{t,2}))}{1+r} - s_{t,2}\delta - p^c_{t,2}s_{t,2} \quad (10)$$

subject to $0 \le s_{t,1} \le C$ where C is the storage capacity.

Again, $s_{t,2}$ is found by setting $\frac{dW^*_{m,t+1,1}}{ds_{t,2}} = 0$ and prices are given by

$p^c{}_{t,2} = \beta_2(h_{t,1} + s_{t,1} - s_{t,2})^{-\alpha_2}$ and $p^l_{t,2} = p^c_{t,2} - T$

III. Results of the New Model and Comparison with Results of the Exogenous Hypothesis

The model above is a complex dynamic system and can only be solved numerically. We run simulations of the model above by varying the values of parameters. We chose intervals for the values of parameters by using evidence from the empirical literature or by using values that seemed plausible[13].

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[12] It seems reasonable to assume that the storage firm is less risk averse than the producer (Stiglitz and Newbery (1981; p. 164), which is reflected in our selection of values for the coefficients of risk aversion of the storage firm and the producer in our simulations. However, to our knowledge, there is no justification (theoretical, nor empirical) to give the producer and the storage firm different expectations schemes.

[13] For α_i, Beghin, Bureau and Drogué (2003) find, for the price elasticity of demand in the South Korean market, values going from -0.8 for pork to -0.19 for rice. This gives α_i coefficients going between 5.3 and 1.25. Here, we

Figure 1 shows some typical series of the prices in the local and central markets over a 200 year period. Both time series are characterized by movements around the mean and sudden peaks. Prices in the central market have higher peaks than those in the local market. High peaks occur during stock-outs, which, in the central market, take place during 19% of periods. These series also exhibit an auto-correlation of first rank, while the chaotic models mentioned earlier typically have a negative first order autocorrelation, which was in part why these models were not considered as being realistic. Thus, it appears that, like in the D&L model, but in a very different context, storage seems to be a key determinant of the first order autocorrelation of agricultural commodity price series.

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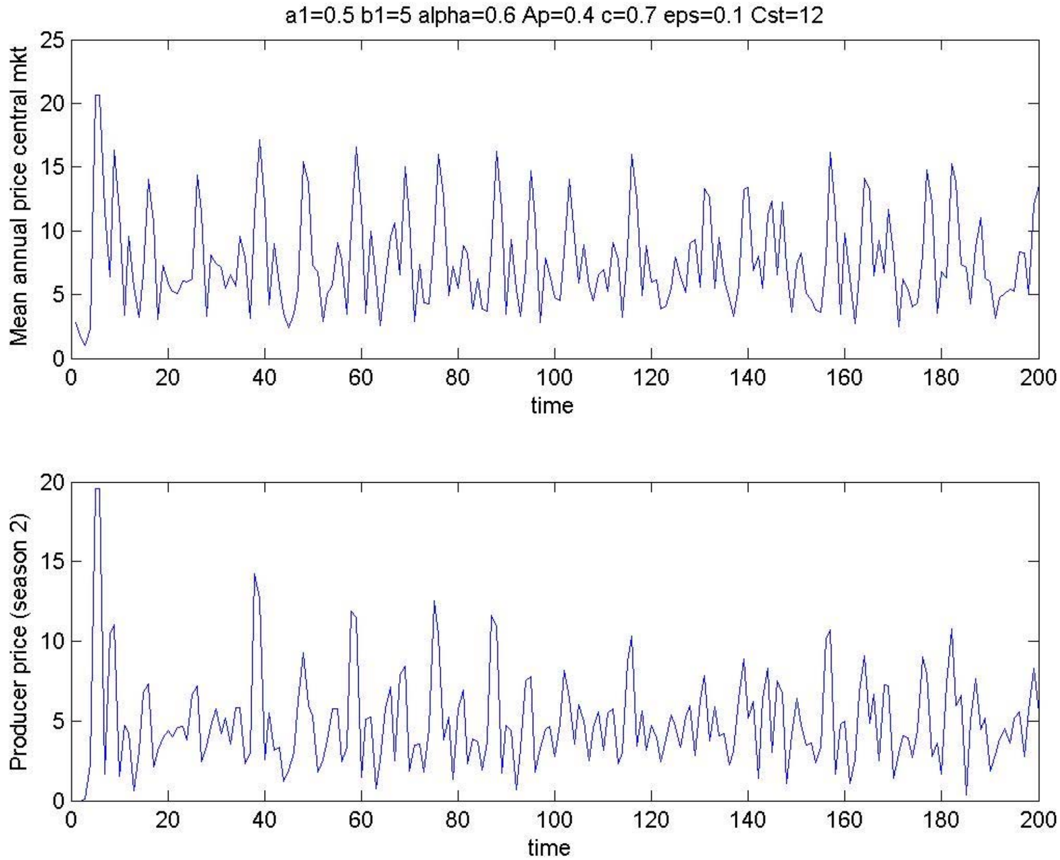
present results for $\alpha_i = 0.6$, but we have also conducted simulations and reached similar results for $1 < \alpha_i < 2$. Regarding the price elasticity of supply, it is well known (and easy to check), that in a Cobb Douglas type of production function with two factors, one fixed, the other one variable with a constant price, and with exponents summing to one, if 's' is the share of the variable factor in the value of output, then the price elasticity of supply is given by s/(1-s) when the marginal cost is equal to the price. In agriculture, land is a fixed input and accounts for about 20% of the value of output. This would give a price elasticity of supply of 0.8/0.2 =4 . If we assume that both land and labor are fixed, and that the share of variable factor is 40%, this gives a price elasticity of supply of 0.4/0.6= 0.66 . The actual price elasticity of supply is likely to be between these two extremes. Here we used a value of a that is close to this lower bound (a= 0.5).

For other parameters, in the absence of empirical evidence, we have chosen values that are deemed plausible, which sometimes is difficult to assess: for instance, in theory, the absolute coefficients of risk aversion, should depend upon the wealth of the decision maker. Now, it is difficult to assess the wealth of our agents in the context of an imperfectly specified numerical exeercise such as this one. In addtion, we have to use a mean absolute coefficient of risk aversion, which is the harmonic mean of individual coefficients. Fortunately, the results of the model are qualitatively similar for a large range of these coefficients (from 0.001 to 10).

Figure 1: Simulated Prices on the Central and Local Markets over 200 Years[14]



The model above is put to a test by following the method used by D&L (1992). We vary several parameters that have been shown to influence price dynamics: the adjustment parameter for adaptive expectations, the interest rate, the absolute risk aversion coefficient and the cost of storage. We assess how the results are affected. Table 1 gives some of the simulation results. It compares the characteristics of five simulated series for the central market with storage, then without storage, those of actual price series of 13 agricultural commodities as presented in D&L (1992), and then simulations from the model of D&L. For each of the simulated series, we include the coefficient of

[14] In all simulations, $a = 0.5; b = 5; \alpha_i = 0.6; \beta_i = 1.3; T = 1.$ In graph 1, other parameter values are as follows: $\lambda_f = 0.1; \lambda_m = 0.1; A_f = 0.4; A_m = 0.35; r = 7\%; \delta = 0.1.$ For the central market, the annual price is the average over two seasons. For the local market, the price is for the summer season. In the local market, there is no exchange and thus no price in autumn.

variation, the first and second order autocorrelation, skewness and kurtosis. For actual series, we include only the mean, maximum and minimum of the 13 commodities for each statistic. All statistics for each commodity are in D&L (1992).

Table 1: Characteristics of Simulated and Actual Series

	Coefficient of variation	AC (1)	AC (2)	Skewness	Kurtosis
Simulations with storage					
(a)	0.51	0.44	-0.5	0.79	3.39
(b)	0.54	-0.33	0.29	0.27	1.66
(c)	0.51	-0.08	0.41	0.94	3.22
(d)	0.3	0.12	0.46	4.64	35.22
(e)	0.48	-0.2	0.3	0.80	3.11
Simulations without storage					
(a)	0.21	-0.19	0.03	-0.63	6.16
(b)	0.24	-0.24	0.03	0.08	5.17
(c)	0.2	0.31	-0.23	0.08	5.17
(d)	0.2	-0.31	-0.23	-1.22	6.65
(e)	0.27	-0.22	0.2	0.62	4.16
Actual Series					
Mean	0.39	0.8	0.61	1.06	2.38
Minimum	0.17	0.62	0.39	0.04	-0.98
Maximum	0.6	0.91	0.82	3.24	16.52
Deaton & Laroque					
Mean	0.35	0.25	0.13	1.92	9.21
Minimum	0.1	0.08	0.01	0.43	-0.29
Maximum	0.53	0.48	0.31	3.41	24.22

Notes: a.c. stands for autocorrelation. In all simulations, $a_i = 0.5; b_i = 5; \alpha_i = 0.6; \beta_i = 1.3; T = 1$, other parameters are :

(a) $\lambda_f = 0.1; \lambda_s = 0.1; A_f = 0.4; A_m = 0.35; r = 7\%; \delta = 0.1$

(b) $\lambda_f = 0.3; \lambda_s = 0.3; A_f = 0.4; A_m = 0.35; r = 7\%; \delta = 0.1$

(c) $\lambda_f = 0.1; \lambda_s = 0.1; A_f = 0.4; A_m = 0.35; r = 10\%; \delta = 0.1$

(d) $\lambda_f = 0.1; \lambda_s = 0.1; A_f = 0.25; A_m = 0.10; r = 7\%; \delta = 0.1$

(e) $\lambda_f = 0.1; \lambda_s = 0.1; A_f = 0.4; A_m = 0.35; r = 7\%; \delta = 0.7$

With coefficients of variation in the [0.30;0.54] range, simulated series tend to be slightly more volatile than actual series, except sugar and cocoa, for which volatility is similar. The first order auto-correlation coefficients are lower for simulated than for actual series: they are in the range of [-0.08;0.44] for simulated series compared to [0.62;0.91] for actual series. Similarly, second order autocorrelation coefficients tend to be lower for simulated series. Simulated series have significant positive skewness, thus exhibiting, like actual series, asymmetric fluctuations. Simulated series have positive kurtosis between 1.66 and 35.22, which is consistent with the "heavy tails" that are a well known feature of sugar and several other commodities price probability distributions. The above results also held when simulations were run over a shorter time span (100 years) in order to be consistent with actual series.

Results from the test of this endogenous price fluctuation model are overall similar to those of the theory of competitive storage. In particular, a major limitation of the work of D&L (1992) was not to be able to reproduce the high autocorrelation of actual series with a maximum autocorrelation coefficient of first order of 0.48. Using the same model as D&L (1992), Cafiero and Wright (2006) later found an autocorrelation coefficient of 0.69 after reducing the cost of storage. With a maximum autocorrelation of first rank of 0.44, our model with endogenous price fluctuations leads to a similar level of autocorrelation of first order.

What is even more interesting is that, in the absence of storage, i.e. when the storage capacity is set at zero but all other parameters are as in figure 1, our model gives series that converge or become periodic. The series of the model without storage thus have less volatility, as shown by the low coefficient of variation in table 1. This result suggests that, in our model, storage has a destabilizing effect, since it contributes to the endogenous fluctuations of prices. This is a preliminary result that requires more research. It stands in contrast to the stabilizing role that has been attributed to storage in the exogenous hypothesis (e.g., Newbery and Stiglitz 1981; Williams and Wright 1991)[15]. This preliminary result makes sense mathematically since storage, and its non-negativity constraint, introduces a non-linearity in the model, a condition that is necessary but not sufficient in order to have a chaotic dynamic. Without storage, the model leads to converging or periodic price series, thus pointing toward the possible destabilizing role storage may play. This result is consistent with results from other literatures. From an economics standpoint, our results are consistent with the theoretical work of MacKey (1989) who finds that price dependent storage has a destabilizing impact on prices. Also, in economic history, Fogel (1989) finds that in England between 1500 and 1800, famines resulted from an extremely inelastic demand for food inventories rather than from weather shocks. Private storage, which has long been considered as having a stabilizing effect on prices, needs to be subject to more research.

To keep this model simple, we have not introduced futures markets in our model[16]. However, because futures markets are a way to store virtually, they should have the same advantages and disadvantages as actual storage, so that the conclusions we reached earlier should also apply. This should comfort analyses that attribute a significant role to speculation in the explanation of the recent crisis (Mitchell (2008 ; p. 15)).

[15] However, in the context of *noncompetitive* storage, Chavas (2008) shows that storage contributes to price fluctuations.

[16] Boussard (1996) has shown that the introduction of futures markets does not change the chaotic dynamics of a cobweb model with risk aversion.

Conclusions

Models of endogenous price fluctuations can thus reproduce the main stylized facts of actual price series for agricultural commodity prices, as model of exogenous price fluctuations do. It is clear however that the former do not perform better than the latter, which leaves room for further research on the origins of price fluctuations. Both approaches thus perform equally well in the empirical test we conducted.

If competitive private storage leads to price volatility, whether price fluctuations are endogenous or exogenous, other methods need to be developed to reduce fluctuations. Such methods are very different depending on the origin of fluctuations: globalization and liberalization are efficient if fluctuations are exogenous, but counter productive if they are endogenous.

Over the last twenty years or so, the market liberalization reforms that swept away many of the institutions that were to stabilize domestic commodity markets do not seem to have reduced fluctuations, on the contrary. This gives support to the work of theorists on endogenous fluctuations. However, we are far from fully understanding this phenomenon,: much more research is needed in this area. This paper provides a modest contribution in this direction.

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