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Optimal Storage in Brazilian Corn Market: application of a rational Dynamic Model

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Abstract. This paper aims to analyze the decision regarding corn storage (for the first and second crops) in the current context of the Brazilian market through an economic model of dynamic storage. We consider storage as a competitive economic activity and that agents can maximize profit through rational expectations. Our results provide a comprehensive analysis of how growth in the Brazilian second crop and high level of exports has impacted corn storage dynamics. The export rule suggests increasing exports when availability exceeds 37.3 million tons in the first crop and 56.3 million tons in availability in the second crop. The storage rule suggests that storage formation occurs increasingly in the first crop when supply exceeds 38.1 million tons and 60.9 million tons in the second crop.

Keywords: Brazilian corn market, commodity price dynamics, storage model.
JEL codes: Q11, C61, D41.

1. INTRODUCTION

The volatility of agricultural commodity prices tends to be high over time, with greater sensitivity to supply shocks due to the biological nature of production, as well as seasonal and cyclical components. The high volatility of agricultural prices poses risks for both producers and consumers. The potential of storage for moderating such risks is widely recognized (Bobenrieth *et al.*, 2013; Cafiero *et al.*, 2011; Miranda, Helmberger, 1988; Williams, Wright, 1991). However, studies that analyze the important recent changes in the Brazilian grain market are scarce.

This paper provides a numerical simulation of the storing strategies in the Brazilian corn market. For that, an economic model is applied to predict optimal storing behavior and ultimately the impact on prices and consumption with different levels of supply.

The possible interest for an international audience is associated with the possibility of replicating the equilibrium equations and the model calibration for different contexts. Also due to the importance of Brazilian production in global trade, Brazil is currently responsible for the second-largest volume of corn exports. A better understanding of the decision to store and export can help international agents operating in this market.

The Brazilian corn market underwent important structural changes, both in the production system with the introduction of the second harvest and in greater integration with the foreign market, via exports (Alves *et al.*, 2018; Mattos, Silveira, 2018). Production jumped from 41.5 million tons in 2000/2001 to 101 million tons in 2018/2019. The development of new seed technologies and expansion of the joint soy and corn production system in the same crop year allowed the Brazilian production of second-crop corn to increase significantly, going from 15% of the total production in 2000/2001 to 73% in 2018/2019. The greater supply was accompanied by an increase of 491% in exports in the same period. With this, Brazil consolidated itself as one of the main corn producers and exporters worldwide (CONAB, 2020; USDA, 2020).

Much of the government policies for controlling agricultural prices and/or managing government stocks frequently implemented in the second half of the 20th century has been extinguished. A detailed discussion of agricultural price policies in Brazil is available in Schwantes & Bacha, 2019. Currently, the decision to store corn in the Brazilian market rests exclusively with the private sector reflecting market conditions.

In this context, the stock-to-use ratio in the Brazilian corn market is lower compared to other main producing countries. Between the 2000/2001 and 2018/2019 harvests, the average stock-use ratio in Brazil was 0.14, while in the same period in the United States it was 0.16, and in China, 0.51(USDA, 2020). The lower stock-to-use ratio tends to reflect higher price volatility and, consequently, higher price risk for producers and consumers (Bobenrieth *et al.*, 2013) demonstrated the relevance of the standard storage model for understanding the relations between stocks and prices of commodities.

This study analyzes the decision to store corn in the recent context of the Brazilian market. Specifically, we propose a dynamic stochastic economic model to analyze private storage under the assumption of rational expectations of agents. Besides, using the calibrated model, we verify the market's responses and the expected prices expressed by quantity stored with different levels of supply.

Due to the peculiar evolution that corn production in Brazil has had in recent decades, none of the preexisting storage models in the literature are adequate to study the corn market in Brazil as it evolved to the current configuration. Thus, this study sought to adapt the existing models in the literature to this new reality in the corn market, incorporating in the model the greater integration to foreign markets via exports and the expansion of second crop production. The impacts of these changes on corn storage activity in Brazil have not yet been discussed previously in the literature.

2. RELATED STUDIES

Literature about storage is extensive and beyond the scope of this paper. The purpose of this section is to present the reader with works that contributed to a better understanding of the decision to stock grain, on the hypothesis that storage competitive market and that agents rationally make decisions.

It is widely recognized in the economic literature that speculative storage activity provides an efficient market-based way to reduce price volatility in commodity markets (Bobenrieth *et al.*, 2013; Cafiero *et al.*, 2011; Miranda, Helmberger, 1988; Williams, Wright, 1991). Agricultural price risk is a concern of both producers and consumers, which justifies an active academic debate on the role of storage regarding agricultural price volatility.

The seminal storage model proposed by Gustafson (1958) presents a numerical solution for the problem of deciding how much to store out of a given available amount of a storable product.

Wright & Williams (1982) revisited Gustafson's (1958) approach by analyzing the storage economy as a dynamic problem. The authors develop numerically and develop polynomial approximations to the function relating expected price and current storage level. The authors demonstrated that the possibility of storage affects producers and consumers.

The extension of the numerical model to the case of competitive supply by producers maximizing expected profits, and holding rational expectations, was introduced by Wright & Williams (1984). In their model, both production and storage begin to respond rationally to economic incentives. Thus, the decisions to produce and store are made by agents who seek to maximize profit in a competitive environment and all form rational expectations.

Miranda & Helmberger (1988) assess the effects of regulatory stocks policy on the U.S. soybean market in which the government attempts to stabilize agricultural prices through open market purchases and sales. The model allows for private storage, government stocks, and expected price-responsive production. Miranda & Glauber (1993) develop a method for systematically estimating a rational expectations commodity market model that explicitly incorporates both private and government stockholding dynamics, in an empirical application to the U.S. soybean market.

Fackler & Livingston (2002) discuss storage management related to the marketing decision of harvested crops. They pointed out that agricultural producers with access to storage have flexibility in choosing the timing and quantities of sales. The decision rule is demonstrated to result in substantial gains from storage.

Williams & Wright (1991) synthesize the modern theory of competitive storage. The authors have a detailed discussion about supply, demand, and market clearing conditions to the intertemporal arbitrage equation. Williams & Wright (1991) and Cafiero *et al.,* (2011) present a wide review of the empirical relevance of the competitive storage model and results from optimal competitive storage under stochastic supply and demand shocks.

Peterson & Tomek (2005) apply the rational expectations competitive storage model to solve the unknown functional forms of expected price in the United States of America corn market. This model is used to examine the performance of this framework in explaining price behavior in an actual commodity market.

With a less price-sensitive consumption demand curve, Cafiero *et al.* (2011) show that storage can generate in their model levels of sample correlations and variation of price in the observed ranges for some commodities. Thus, the relevance of the storage model is re-established as an empirical question.

Serra & Gil (2013) studied US corn price observed from January 1990 to December 2010 by allowing for the influence of ethanol markets, corn stocks forecasts, and macroeconomic conditions. The results showed the impacts of stocks-to-disappearance forecasts in the short run are very high relative to the effects of energy price and macroeconomic instability.

Bobenrieth *et al.* (2013) have presented a procedure to construct, using global commodity price data and a commodity storage model estimated on those price data and stocks-to-use ratios. The results suggest that stock data can be valuable complements to imperfect price data as indicators of vulnerability to shortages and price spikes.

Guerra *et al.* (2015) explored the limits of econometric estimations of the standard commodity storage model. They present the application of a maximum likelihood estimator of the storage model using the case of the United States corn price.

Zhou & Babcock (2017) use the competitive storage models to estimate the impact of ethanol and fueling investment on corn prices in the United States. The results showed that corn prices could decrease by 5% or 6% if the US biofuel mandates were to be reduced.

Oglend & Kleppe (2017) have investigated the commodity price implications of bounded speculative storage. Storage capacity introduces another source of limits-to-arbitrage in commodity markets. In general, a fixed capacity reduces the shock smoothing effect of storage.

Only two papers of this nature studied the Brazilian grain market. Guimarães & Barros (2006) analyzed the corn market through dynamic models of rational expectations with data from 1986 to 2000. The authors show that the opening of the market transfers to the external trade part of the role of buffering internal supply and demand shocks.

Bragagnolo *et al.* (2009) analyzed the decision to store rice in Brazil using dynamic models of rational expectations capable of capturing the effects of imports and policies to sustain producer prices adopted by the Brazilian government. The authors demonstrate that, in the presence of storage activity, there is less dispersion of consumption over time, which makes the variation of prices lower.

3. THE RATIONAL STORAGE MODEL

The storage problem can be understood as the allocation of a given quantity of product between current consumption and the formation of stocks for future consumption.

In a perfectly competitive economy, it would be economically viable for an individual agent to store one more unit of product, as long as the difference between the expected price and the current price is greater than or equal to the storage cost.

Our empirical estimation follows the approach of Williams & Wright (1991), and adaptations for the Brazilian case proposed by c. This method allows predicting optimal storing behavior with different levels of supply and the respective variations on prices and quantity consumed.

In recent years, corn production in Brazil on a large scale occurs in two periods in the same crop year[1]. In this context, we propose a dynamic stochastic economic model to analyze private corn storage in the first and second harvests. The characteristics of each period are evaluated.

The simulation models assume that the data of the first corn crop refer to the first semester of the year (the period in which the harvest and commercialization of the crop are concentrated), while the data of the second crop refer to the second semester.

[1] More details on the characteristics of grain production and marketing in Brazil are showed by Alves *et al.* (2018).

Keeping these parameters constant for all periods, the problem becomes stationary and, therefore, it is possible to find the optimal storage rule for equilibrium. In addition to the hypothesis that stocking activity is a competitive activity, the model assumes a constant return of scale in land use and the existence of neutrality about risk. That is, the economic agents involved in the economic process are neutral for the risk inherent in the storage activity (Bragagnolo *et al.*, 2009).

Technical details of the estimation procedure can be found in Williams & Wright (1991). We present a general overview of the method in Appendix Awith the steps of the different functions.

4. PARAMETERS SPECIFICATION

The parameters used to calibrate the model are based on the Brazilian corn market between the crop years 2000/2001 and 2018/2019. Pieces of information on corn supply and demand in Brazil are presented in Appendix B.

The method used requires the following parameters: the relationship between domestic consumption and prices, domestic consumption shocks, expected profit per area, supply shocks, average export price, the cost of storage, the real interest, and storage losses.

The relationship between domestic corn consumption and domestic corn prices were estimated by ordinary least squares, where the semiannual average of domestic consumption was the independent variable. It was estimated based on the amount of domestic consumption per crop year released by the National Supply Company (CONAB, 2020). It was assumed that domestic consumption occurs linearly throughout the year. The daily prices of corn for the region of Campinas/SP released by the Center for Advanced Studies in Applied Economy - Cepea/Esalq/USP were used as a reference for domestic prices with values for the period 2001- 2019. The prices were deflated by the official Prices General Index – Internal Availability (IGP-DI) for December 2019 and it was used to calculate the semiannual price average.

To estimate shocks in consumption, residues were computed based on the regression of demand for consumption. From the residues, a normal probability distribution of a zero mean and standard deviation of each sample (first and second crops) was simulated for 8 equally spaced values. The lowest and highest values are considered equivalent to the 99% confidence interval of the distribution.

The relationship between the planted area and the expected profit per acre is estimated by ordinary least squares. The production cost is an independent variable. The planted area data and the cost of production were obtained from Conab. All data were deflated by the IGP-DI to December 2019 values.

The productivity frequency distribution of the first and second corn crops was calculated by the average productivity between crops 2000/2001 and 2018/2019 released by (CONAB, 2020), disregarding the trend of productivity gain over the period. From the mean and standard deviation of both the first and second crops yield series, two normal distributions were generated, one for each crop, with 16 values each, equally spaced, with the highest and lowest values equivalent to the confidence interval of 99 % of the distribution.

The average prices of the first and second semesters were calculated from the average monthly price of Brazilian corn exported values for the period 2001 to 2019, released by the Ministry of Industry, Foreign Trade and Services. All data were deflated by the IGP-DI to December 2019 values.

The storage cost was calculated based on the information released by the Storage Information System (Siarma/Esalq-Log/Esalq/USP, 2020).

The Selic interest rate (which is the basic interest rate in Brazil) has been adjusted to remove the effects of inflation to reflect the real interest rate in December 2019. It was based on domestic inflation rates (IGP-DI) between 2001 and 2019.

Our model considers the fixed deterioration of inventories or storage losses of 1.5% per year. It was based on the works of Faroni, Barbosa, Sartori, Alenar, 2005; Siarma/Esalq-Log/Esalq/USP, 2020.

The generation of random numbers, the frequency distribution of variables, the relationship between consumption and prices, the demand function, and the relationship between expected profit per area were made using the statistical program R. All other numerical calculations and procedures were performed using an electronic spreadsheet.

We calibrate the model described in Section 3 assuming parameters specification reported in Table 1.

5. THE OPTIMAL STORAGE RULE IN THE FUNCTION OF THE EXPECTED PRICE AND PLANTED AREA

As mentioned above, the analyses consider as periods the first and second semesters of each year. The estimation of the algorithm for the functions of the expected price and the expected area begins with the definition of a vector of *n* elements, equally spaced, for the ending storage in the previous period *(t-1)*. In this model,

Tab. 1. Parameters specification.

Parameters	First crop	Second crop
The relationship between domestic consumption and prices		
- Constant	1.042,92	1.053,30
- Angular coefficient	-0,0118	-0,0136
Domestic consumption shocks		
- Mean	0,0000	0,0000
- Standard deviation	4.294,58	3.455,44
Expected profit per area (acres)		
- Constant	10.713,88	25.310,29
- Angular coefficient	0,234	0,4133
Supply shocks		
- Average productivity (tons/acres)	1,7357	1,63
- Standard deviation	0,1646	0,3066
Real interest rate (%/ year)	*5,3367*	*5,3367*
Storage losses (%/ton/year)	*1,5*	*1,5*
Storage cost (R$/ton)	5,06	5,06
Average export price (R$/ton)	601,8248	582,465

Note: Standard errors are in parentheses.
Source: Research results.

29 storage values were defined, spaced by 500 thousand tons, between zero and 14 million tons. The definition of this set of values was based on the context of the Brazilian corn market.

The multiplication of the planted area and the 16 possible values of productivity gave rise to 16 values of total production for each of the 29 initial values of storage, thereby generating 464 different values of products in the period. The initial availability of the model is generated from the sum of preliminary storages and domestic production, less physical losses during storage.

In this simulation, 8 values were used for each demand shock in period t. Total availability resulted from the sum between initial availability and demand shocks, generating a simulation of 3.712 values.

The decision of the farmer to store or not is taken on the basis of the expected price, storage costs, interest rate, storage losses, and area and demand functions. The optimal storage rule to different levels of product availability (initial stocks plus current production) is exposed in Figure 1. It is worth mentioning that stocks in the domestic market only occurs when the profit prospect of storing the commodity is greater than that from exporting it.

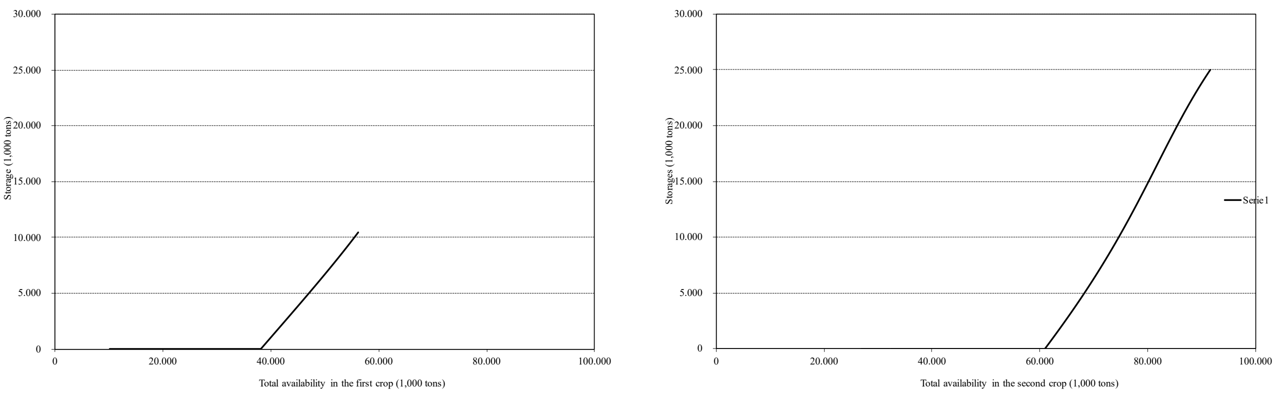
The formation of storage in any given period (year) occurs when availability exceeds 38.01million tons from the first crop and when it exceeds 60.9 million tons from the second crop (Fig. 1). Availability lower than these values would lead to no stock formation.

The parameters of the expected price equations $E(Pt+1)$ as a function of the storage(S_t) of the previous period were approximated by fourth-degree polynomials from the results obtained in the model simulations. So for any period t:

$$E(P_{t+1}) = 1.85497*10^{-16}*S_t^4 + 5.12895*10^{-12}* S_t^3 + 8.13277*10^{-8}* S_t^2 - 1.06156*10^{-2}*S_t + 724.527603.$$

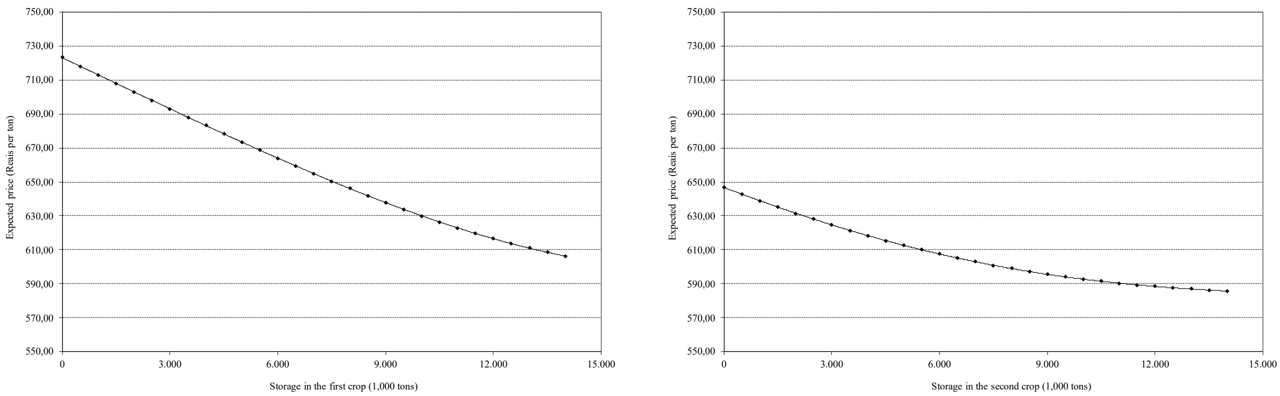
For the first crop (period 1), the results of the simulation indicate that when there is no preliminary storage ($S_0 = 0$), the expected price for the next period is R$ 724.53 per ton.

Fig. 1. Storage Rule.



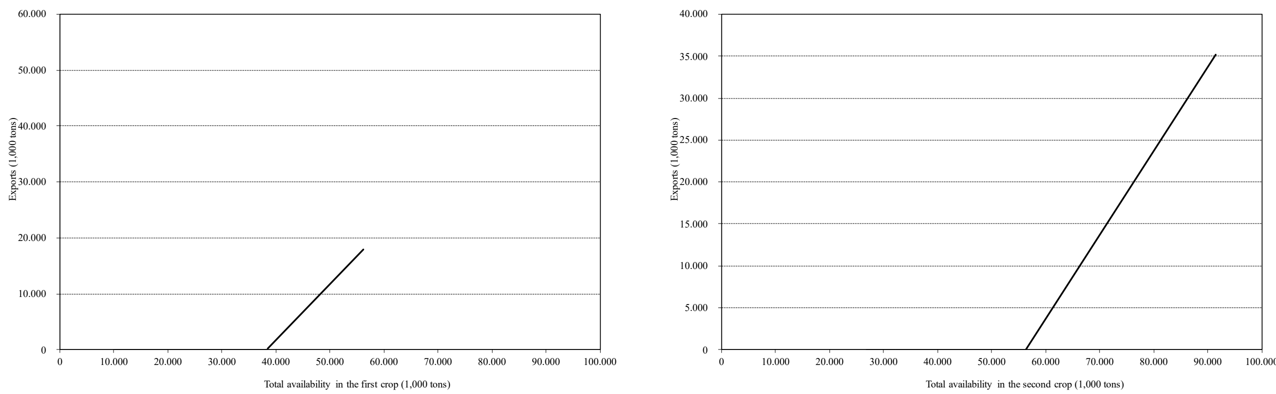
Source: Research results.

Fig. 2. Expected price based on storage.



Source: Research results.

Fig. 3. Exports based on supply.



Source: Research results.

For the second harvest, the results indicate that when the final storage of the previous crop is zero, the expected price is R$ 646.72 per ton. The equation of the expected price for the second crop as a function of the storage of the previous crop is presented below:

$$E(P_{t+1}) = -4.39569*10^{-16}*S_t^4 + 1.03133*10^{-11}* S_t^3 + 2.04989*10^{-7}* S_t^2 - 8.04279*10^{-3}*S_t + 646.72501$$

The higher the storage levels, the lower the price level expected for the next period. Figure 2 shows the expected price according to the storage found in the model for the simulations referring to the first and second crops.

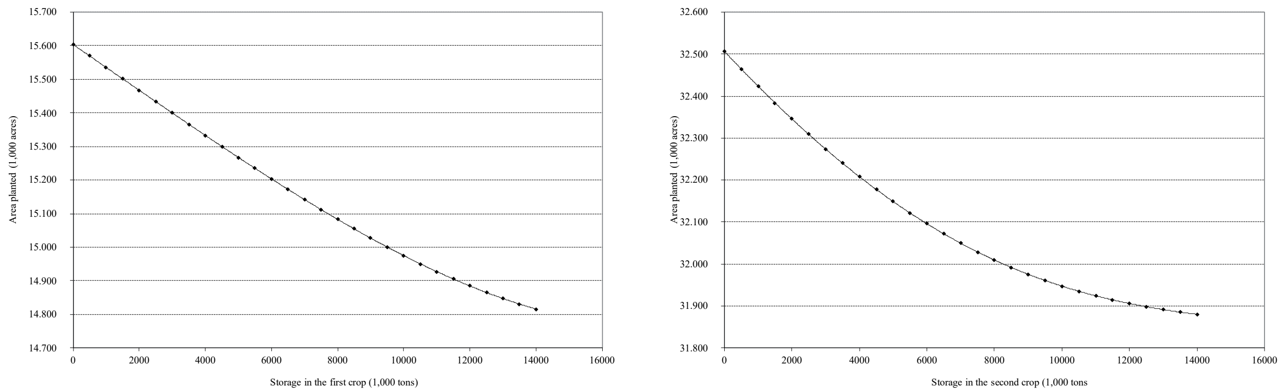
Model simulations indicate that exports during the first crop start when supply reaches 37.3 million tons. During the second crop, the period of greatest corn supply in the Brazilian market, exports occur in greater quantities. Exports start when availability reaches 56.3 million tons and increase up to 35.2 million tons when supply is approximately 91.5 million tons.

From the simulated values, it is possible to define an export rule to corn availability, assuming the assumptions and parameters considered in this model. Figure 3 shows the export quantities according to the supply found in the model.

The parameters of the equation of the area to be planted (A_{t+1}) as a function of the ending storage of the previous period (S_t) were approximated by fourth-degree polynomials from the results obtained in the simulations of the model. The simulations indicate that the higher the final storage of the previous crop the lower the expected price, and consequently, the lower the planted area.

For the first harvest, the simulations indicate that the largest planted area is 15.6122 million acres when the ending storage of the previous period is zero and decreasing successively as the ending storage of the pre-

Fig. 4. Area planted based on storage.



Source: Research results.

vious period increases. The polynomial used to describe the planted area of the first crop as a function of the ending storage of the previous period is presented below:

$$A_{t+1} = 1.06647*10^{-15}*S_t^4 + 4.03052*10^{-11}* S_t^3+5.11583*10^{-7}* S_t^2- 7.15466*10^{-2}* S_t + 15.6122$$

For the second crop, the simulations indicate that the maximum observed area is 32.500 million acres when the ending storage of the previous period is zero. The polynomial used to describe the planted area of the second crop to the ending storage of the previous period is presented below:

$$A_{t+1} = -4.84389*10^{-15}*S_t^4 + 1.02693*10^{-10}* S_t^3 + 2.44394*10^{-6}*S_t^2 - 8.58213*10^{-2}* S_t + 32.5069*10^4$$

Figure 4 shows the area planted according to the storage found in the model for the simulations referring to the first and second crops.

6. CONCLUDING REMARKS

The model purposed to analyze the decision to store corn from the perspective that storage is a competitive economic activity and that agents are profit maximizers. The decision to store corn is taken in the context of the recent structural changes in the Brazilian market, with the greater participation of the second crop in total production and increasing exports.

The simulations show that expansion of production, consequently greater cereal supply is accompanied by increasing levels of storages and exports. The simulations corroborate the trend of expansion of the production of second-crop corn in Brazil, and, consequently, higher levels of supply, export, and storage. Actual data on prices, corn supply, and demand in Brazil are presented in Appendix B.

The results suggest the strong influence of external demand, via exports, under the dynamic equilibrium of the Brazilian corn market. With the expansion of domestic production, mainly of corn produced in the second crop, the levels of storage and export balance are increasing, supported by the greater cereal surplus and pressure on domestic prices.

The supply of corn in Brazil has increased expressively in recent years with the expansion of second-crop corn production. Actual data show that corn production in Brazil was significantly higher than consumption in recent years, for example in 2016/2017 crop production was 70% higher than consumption. The greater supply of the commodity enabled increases in exports and the quantity stored. After the 2012/2013 crop, Brazilian production has surpassed 80 million tons, a period in which there was a large increase in the stock-consumption ratio (Appendix B).

The calculated export rule suggests increasing exports when availability exceeds 37.3 million tons in the first crop and 56.3 million tons in availability in the second crop. The calculated storage rule suggests that storage formation occurs increasingly in the first crop when supply exceeds 38.1 million tons and 60.9 million tons in the second crop.

Between the 2000/2001 and 2018/2019 harvests, Brazilian corn exports rose from 5.9 to 41.2 million tons, while public stocks ranged from 347 thousand tons to 19.2 million tons (Appendix B). Exports proved necessary for the balance between supply and demand and, consequently, profitable prices for farmers.

The expected prices are inversely related to the ending storages of the previous period, as expected. As already discussed by Bragagnolo *et al.* (2009), in the presence of stocking activity, there is a lower dispersion of consumption over time, which makes the variation of prices lower. Actual data show that prices showed higher price levels when the quantity in inventories was lower. For instance, the prices of the first crop 2014/2015 increased from R$ 586 per ton to R$ 923 per ton in the following harvest, in the same period the stock-to-use ratio dropped from 23.3% to 16.3 % (Appendix B). Our results suggest that for levels of equilibrium storages, higher price levels are expected in the first crop compared to equilibrium prices for the second crop.

In Brazil, most of the supply has been concentrated in the second harvest in recent years, which is why exports take place in greater quantities in the second half. With greater integration with the foreign market, prices have shown a higher level in the second half (Appendix B). The context was observed in our simulation.

With the greater volume of exports, the foreign market imposes a price range for the Brazilian market. As described by Guimarães & Barros (2006) the effect is similar to that intended by a policy of regulatory storages, but without the government building inventories. Our simulations show that the storage formed by agents in a competitive economy also occurs within this price range, which in turn follows the oscillations of the international market.

The results of this study should not be compared to the values observed in previous years. The implemented model considers the initially established parameters constant over time, while in previous years these parameters were not constant (Guimarães, Barros, 2006).

The possibility of updating the parameters established initially and finding market equilibrium in the different contexts is the main contribution of this type of study. This paper advances the modeling of storage when analyzing the storages in two periods within the same crop year and the current context of the Brazilian corn market. This study provides a comprehensive analysis of how growth in the Brazilian second crop and high level of exports has impacted corn storage dynamics.

Low levels of commodity storages to consumption can imply high price volatility, and greater risk for farmers and consumers as discussed by Bobenrieth *et al.* (2013). Our results should offer useful insights for policymakers, risk-management strategies adopted by farmers, processors, and merchandisers operating in Brazil.

REFERENCES

Alves L.R.A., Barros G.S. de C., Sanches A.L.R., Ribeiro R.G., Osaki M. (2018). *Estrutura de mercado e formação de preços na cadeia produtiva de milh*o. In Alves L.R.A., Bacha C.J.C. (eds.), Panorama da Agricultura Brasileira: Estrutura de mercado, comercialização, formação de preços, custos de produção e sistemas produtivos (1st ed., pp. 133-176). Campinas: Alínea.

Bobenrieth E., Wright B., Zeng D. (2013). Stocks-to-use ratios and prices as indicators of vulnerability to spikes in global cereal markets. *Agricultural Economics (United Kingdom)*, 44(suppl 1): 43-52. https://doi.org/10.1111/agec.12049

Bragagnolo C., Guimarães V.D.A., Barros G.S. de C. (2009). A regra ótima de armazenamento de arroz no Brasil. *Economia Aplicada*, 13(1): 153-181. https://doi.org/10.1590/S1413-80502009000100007

Cafiero C., Bobenrieth H. E.S.A., Bobenrieth H. J.R.A., Wright B.D. (2011). The empirical relevance of the competitive storage model. *Journal of Econometrics*, 162(1): 44-54. https://doi.org/10.1016/j.jeconom.2009.10.008

CEPEA/ESALQ/USP. (2020). *Center for Advanced Studies in Applied Economy*. Available at: https://www.cepea.esalq.usp.br/br/indicador/milho.aspx

CONAB. (2020). *Companhia Nacional de Abastecimento. Produtos e Serviços. Safras*. Séries Históricas. Available at: http://www.conab.gov.br/conteudos.php?a=1253&t=2 (accessed on 30 June 2020).

Fackler P.L., Livingston M.J. (2002). Optimal Storage by Crop Producers. *American Journal of Agricultural Economics*, 84(3): 645-659. https://doi.org/10.1111/1467-8276.00325

Faroni L.R.D., Barbosa G.N. de O., Sartori M.A., Alenar E.R. de (2005). Avaliação qualitativa e quantitativa do milho em diferentes condições de armazenamento. *Engenharia Na Agricultura*, 193-201.

Guerra E.A., Bobenrieth H. E.S.A., Bobenrieth H. J.R.A., Cafiero C. (2015). Empirical commodity storage model: The challenge of matching data and theory. *European Review of Agricultural Economics*, 42(4): 607-623. https://doi.org/10.1093/erae/jbu037

Guimarães V.D.A., Barros G.S.A. de C. (2006). Análise do armazenamento de milho no Brasil em um mercado de economia aberta. *Revista de Economia e Sociologia Rural*, 44(4): 751-771. https://doi.org/10.1590/s0103-20032006000400007

Gustafson R.L. (1958). *Carryover levels for grains: a method for determining amounts that are optimal under specified conditions* (Technical). Washington DC: USDA.

Mattos F., Silveira R.F. da (2018). The Expansion of the Brazilian Winter Corn Crop and Its Impact on Price Transmission. *International Journal of Financial Studies*, 6(2): 45. https://doi.org/10.3390/ijfs6020045

Miranda M.J., Glauber J.W. (1993). Estimation of Dynamic Nonlinear Rational Expectations Models of Primary Commodity Markets with Private and Government Stockholding. *The Review of Economics and Statistics*, 75(3): 463-470. https://doi.org/10.2307/2109460

Miranda M.J., Helmberger P.G. (1988). The Effects of Commodity Price Stabilization Programs. *The American Economic Review*, 78(1): 46-58. https://doi.org/10.2307/1814697

Oglend A., Kleppe T.S. (2017). On the behavior of commodity prices when speculative storage is bounded. *Journal of Economic Dynamics and Control*, 75: 52-69. https://doi.org/10.1016/j.jedc.2016.11.007

Peterson H.H., Tomek W.G. (2005). How much of commodity price behavior can a rational expectations storage model explain? *Agricultural Economics*, 33(3): 289-303. https://doi.org/10.1111/j.1574-0864.2005.00068.x

Schwantes F., Bacha C.J.C. (2019). Análise da formulação da política de garantia de preços mínimos no Brasil pela ótica da economia política. *Nova Economia*, 29(1): 161-192. https://doi.org/10.1590/0103-6351/3926

Serra T., Gil J.M. (2013). Price volatility in food markets: Can stock building mitigate price fluctuations? *European Review of Agricultural Economics*, 40(3): 507-528. https://doi.org/10.1093/erae/jbs041

Siarma/Esalq-Log/Esalq/USP. (2020). Storage Information System. Available at: https://esalqlog.esalq.usp.br/en/storage-information-system-siarma

USDA. (2020). United States Department of Agriculture. Foreign Agricultural Service (FAS). Available at: https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery (accessed on 07 June 2020).

Williams J.C., Wright B.D. (1991). *Storage and commodity markets*. Cambridge: Cambridge University Press.

Wright B.D., Williams J.C. (1982). The Economic Role of Commodity Storage. *The Economic Journal*, 92(367): 596-614. https://doi.org/10.2307/2232552

Wright B.D., Williams J.C. (1984). The Welfare Effects of the Introduction of Storage. *The Quartely Journal of Economics*, 99(1): 169-192. https://doi.org/10.2307/1885726

Zhou W., Babcock B.A. (2017). Using the competitive storage model to estimate the impact of ethanol and fueling investment on corn prices. *Energy Economics*, 62: 195-203. https://doi.org/10.1016/j.eneco.2016.12.017

APPENDIX A. THE RATIONAL STORAGE MODEL

Each producer individually decides how much area he is willing to allocate to planting by maximizing the expected profit ($E\Pi_t^i$). In our model, the planted area by producer i in crop year t is defined by A_t^i; and productivity in crop year t is defined by y_t, and price of the commodity by P. The function of profit expected ($E\Pi_t^i$) by the producer i in period t can then be restated as:

$$E\Pi_t^i = \frac{1}{1+r} E_t(P_{t+1} \times y_{t+1}) \times A_t^i - C_t(A_t^i) \quad (1)$$

Specifically for the simulation model:

$$y_t = \mu + \varepsilon_t$$
$$\varepsilon_t \sim (0, \sigma_\varepsilon^2)$$

The present value of the income expectation is given by the expectation of the revenue per acre $E_t(P_{t+1} \times y_{t+1})$, that is the product of the price (P) in crop year $t + 1$ and productivity y_{t+1} multiplied by the planted area. The expectation is discounted by the interest rate r. The cost of production (C_t) is defined as a function of the planted area. In the case of competitive equilibrium, with zero economic profit, $E\Pi_t^i$. Then:

$$\frac{1}{(1+r)} E_t(P_{t+1} \times y_{t+1}) \times A_t^i = C_t(A_t^i) \quad (2)$$

Based on the first-order condition of the agents' problem of profit maximization, the farmer chooses the planted area. With perfect competition, the marginal cost per acre is equal to the marginal profit per acre. The function can then be presented as:

$$\frac{\partial E\Pi_t^i}{\partial A_t^i} = \frac{1}{(1+r)} E_t(P_{t+1} \times y_{t+1}) - \frac{\partial C_t(A_t^i)}{\partial A_t^i} = 0 \quad (3)$$

$$\frac{1}{(1+r)} E_t(P_{t+1} \times y_{t+1}) = \frac{\partial C_t(A_t^i)}{\partial A_t^i} \quad (4)$$

From the equilibrium condition defined by equation (4), the farmer defines the area to be planted:

$$A_t = A[E_t(P_{t+1} \times y_{t+1})] \quad (5)$$

It is assumed that the planted area has a positive relationship with the expected price:

$$\frac{\partial A_t}{\partial E_t(P_{t+1} \times y_{t+1})} > 0 \quad (6)$$

The production x in the year t, is the result of the planted area in the previous period multiplied by the expected productivity in t:

$$x_t = A_{t-1} \times y_t \tag{7}$$

The quantity consumed (Q_t) in period t can be represented by the following relation $Q_t=I_t - S_t$ where S_t is the quantity stored in period t for period $t + 1$, and I_t is the domestic availability in period t. That is, the domestic availability (I_t) is the result of the sum between the quantity consumed (Q_t) and the storage (S_t),

$$I_t=S_t + Q_t. \tag{8}$$

The product availability in period t can also be expressed as:

$$I_t = x_t + (1 - \theta)S_{t-1} \tag{9}$$

The product due to storage in the previous period (S_{t-1}) is added to the current period production to obtain the quantity of domestic supply. The physical loss of product due to storage is incorporated into the models by the parameter $0 \leq \theta \leq 1$.

Intertemporal price arbitrage results in the optimal amount of storage. The agents will store the commodity until the marginal storage cost (k) added to the current product price (P_t) is equal to the expectation of price in the following period ($E_t P_{t+1}$) discounted to present value by the interest rate r considering the physical loss of product (θ).

$$\left(\frac{1-\theta}{1+r}\right)(E\mathrm{P}_{t+1}) = P_t + k \tag{10}$$

The price is defined utilizing the inverse demand of consumption for a given produced quantity (Q_t). In addition to the quantity, we consider a random shock associated with the inverse demandin year t, as expressed below:

$$P_t = P(Q_t, \vartheta_t) \tag{11}$$

Especifically, for the simulation model:

$$P_t = a + b\vartheta_t \; ; \; \vartheta_t \sim (0, \sigma_\vartheta^2)$$

For an open economy, the possibility of exporting should be incorporated for the calculation of the level of domestic supply. The model considers only exports since it is understood that Brazilian corn imports were insignificant compared to the quantity produced in the analyzed period.

As a condition of international trade, agents will export when the level of export price is higher than the domestic price; otherwise export will not occur. Therefore the following constraints are imposed on the model:

$$\begin{aligned} M_t > 0, \text{if } P_t^{EXP} - P_t \geq 0 \\ M_t = 0, \text{if } P_t^{EXP} - P_t < 0 \end{aligned} \tag{12}$$

where P_t^{EXP} is the export price and, M_t is the quantity exported, in year t. International trade is incorporated into domestic availability by the equation:

$$I_t = x_t + (1-\theta)S_{t-1} - M_t \tag{9'}$$

Considering (9') and (8), the domestic availability (I_t) can be used for current consumption or storage:

$$I_t = x_t + (1-\theta)S_{t-1} - M_t = Q_t + S_t. \tag{13}$$

Storage will occur in period t, when the expectation of prices in *(t+1)*, that is, ($E_t P_{t+1}$), net of the physical storage loss of product (θ), discounted to value present is higher than the price in period t, added to the marginal cost of storage k. The intertemporal rule for storage activity can be represented as:

$$\begin{aligned} S_t \geq 0, \text{if} \left(\frac{1-\theta}{1+r}\right)(E\mathrm{P}_{t+1}) \geq P_t + k \\ S_t = 0, \text{if} \left(\frac{1-\theta}{1+r}\right)(E\mathrm{P}_{t+1}) < P_t + k \end{aligned} \tag{14}$$

It is assumed that the agents' choices are optimized from the perspective of rational expectations. The expected price for period $t + 1$ is a function of the storage to be formed in the period t and the storage, production, and exports in the following period $t + 1$.

$$E_t P_{t+1} = f((1-\theta)S_t + x_{t+1} - S_{t+1} - M_{t+1}) \tag{15}$$

The positive quantity to be stored in period t is defined by the following expression:

$$\left(\frac{1-\theta}{1+r}\right)(E_t P_{t+1}) - P_t(Q_t) - k = 0 \tag{16}$$

By replacing equations (13) and (15) in equation (16) the quantity to be stocked can then be restated as:

$$\begin{aligned} &\left(\frac{1-\theta}{1+r}\right) f[(1-\theta)S_t + x_{t+1} - S_{t+1}) - M_{t+1}] - \\ &P_t[(1-\theta)S_{t-1} + x_t - \mathrm{M}_t - S_t + \vartheta_t] - k = 0 \end{aligned} \tag{17}$$

The goal is to identify the amount of storage that maximizes the gains of the agents using equation (17). By keeping the parameters constant over time, the problem of storage optimization becomes stationary. The convergence of the parameters is sought through computational methods of simulation, thus defining the optimal rule of constant storage over the years.

Appendix B. Corn supply, demand, and prices in Brazil.

Crop	Beginning Stocks (1,000 tons)	1º Crop Production (1,000 tons)	2º Crop Production (1,000 tons)	Total Production (1,000 tons)	Imports (1,000 tons)	Supply (1,000 tons)	Consum-ption (1,000 tons)	Exports (1,000 tons)	Ending Stocks (1,000 tons)	Stocks to Use Ratio (%)	Price in 1º crop* (R$/ton)	Price in 2º crop* (R$/ton)
2000/01	3,591	35,833	6,457	42,289	549	46,429	34,449	5,918	6,062	*17.6*	519.93	726.49
2001/02	6,062	29,086	6,181	35,281	362	41,705	36,358	2,509	2,838	*7.8*	712.24	1112.66
2002/03	2,838	34,614	12,797	47,411	806	51,055	37,463	4,050	9,542	*25.5*	929.45	788.62
2003/04	9,542	31,554	10,574	42,129	299	51,970	38,707	4,688	8,575	*22.2*	772.71	699.72
2004/05	8,575	27,298	7,708	35,007	596	44,178	40,410	883	2,885	*7.1*	651.79	672.89
2005/06	2,885	31,809	10,706	42,515	1,011	46,411	40,811	4,340	1,260	*3.1*	540.23	726.10
2006/07	1,260	36,597	14,773	51,370	1,164	53,794	42,584	10,863	347	*0.8*	699.65	912.18
2007/08	347	39,964	18,688	58,652	652	59,652	44,962	7,369	7,321	*16.3*	861.92	717.08
2008/09	7,321	33,655	17,349	51,004	1,182	59,506	46,601	7,334	5,571	*12.0*	645.50	619.96
2009/10	5,571	34,079	21,939	56,018	389	61,978	47,793	10,882	3,303	*6.9*	534.29	687.51
2010/11	3,303	34,947	22,460	57,407	764	61,474	49,963	9,278	2,232	*4.5*	802.89	803.54
2011/12	2,232	33,867	39,113	72,980	776	75,988	51,108	22,293	2,587	*5.1*	689.86	803.52
2012/13	2,587	34,577	46,929	81,506	893	84,986	52,576	26,163	6,246	*11.9*	694.90	589.95
2013/14	6,246	31,653	48,399	80,052	789	87,087	53,676	20,883	12,528	*23.3*	660.01	555.20
2014/15	12,528	30,082	54,591	84,672	315	97,516	54,651	30,131	12,734	*23.3*	586.01	641.12
2015/16	12,734	25,758	40,773	66,531	3,336	82,601	54,837	18,847	8,916	*16.3*	923.86	800.50
2016/17	8,916	30,462	67,381	97,843	953	107,712	57,644	30,813	19,255	*33.4*	603.03	563.97
2017/18	19,255	26,811	53,899	80,710	901	100,865	60,945	23,742	16,178	*26.5*	722.40	671.83
2018/19	16,178	25,647	73,178	100,046	1,596	117,820	65,716	41,173	10,931	*16.6*	669.61	686.40
Maximum	19,255	39,964	73,178	100,046	3,336	117,820	65,716	41,173	19,255	*33.4*	929	1,113
Minimum	347	25,647	6,181	35,007	299	41,705	34,449	883	347	*0.8*	520	555
Average	6,946	32,015	30,205	62,285	912	70,144	47,961	14,851	7,332	*14.7*	696	725

Note * First-half average of the CEPEA-ESALQ/BM&FBove spa for real corn daily index (Campinas, SP); **Second-half average of the ESALQ/BM&FBove spa for real corn daily index (Campinas, SP).
Source: Research (CEPEA/ESALQ/USP, 2020; CONAB, 2020).