The Impact of Production Technology on Dynamic Behavior of Brazilian Farm Milk Prices

Andre Rozemberg P. Simões*
Roberto Max Protil
Universidade Federal de Viçosa – Minas Gerais, Brasil
Departamento de Economia Rural, Sala 105.

Charles Nicholson
Andrew Novakovic
Cornell University – New York, USA.
The Charles H. Dyson School of Applied Economics and Management
Warren Hall, Room 451.

*Corresponding author: andrerpsimoes@hotmail.com

Abstract

The Brazilian farm milk production sector is composed of a myriad of production systems and technological combinations. Low productivity per cow productivity predominates, particularly for small-scale producers. However, there are few studies that explore the effects of this condition on the price oscillations in the long-term. We develop a Systems Dynamics simulation model to test the hypothesis that the improvement of technology in herd management can reduces the oscillations in the price paid to dairy farmers. The main result is that exogenous shocks in the production costs, and the income of the population result in different farm milk price oscillation frequencies, amplitudes, and persistence when the set of parameters that define the technology of Brazilian dairy farms are changed.

Keywords: Dairy production, Technology, System Dynamics, Milk price.

1. Introduction

Brazil was the world's fourth largest cow's milk producer with 32.6 billion liters per year in 2016, surpassed only by the India (154 billions), United States (96.3 billions) and China (37,3 billions)[1]. Although increases in milk produced per cow have been observed in Brazil during the past two decades, cow's productivity is still low (1,304 liters/cow/year) relative to the largest milk producing countries for instance United States (10,327), New Zealand (4,317), and European Union countries (6,434) (USDA, 2016).

Farm milk in Brazil is produced by 1.4 million farmers (25% of all farms) that are widely dispersed throughout the country and the characteristics of which are influenced by social, cultural, and climatic factors. According to Gomes (2006), technology use in Brazilian dairy production is bi-modal, where some producers use technology such as irrigation system, pasture fertilizing and rotation, early weaning, adequate use of concentrated ration, artificial insemination to achieve high levels of milk production per cow and farms that employ less sophisticated technology , and have lower productivity. The use of technology is correlated with

[1] Indian production includes buffalo's milk given its substitutability with cow's milk. European Union production was 156.4 billion liters.

farm size: the Brazilian official database (IBGE) indicates that only 25% of dairy farms own more than 50 hectares, these farms also own the majority of cows and produce 51% of the milk. The other 75% are essentially small farmers that can be considered in a more vulnerable from a social, technologic, and economic perspective and have difficulty accessing and assimilating new technologies.

The outcomes associated with limited technology adoption in agriculture sectors of the developing world is well documented in the literature and is often considered one of the underlying causes of low productivity of rural assets, higher costs and lower profitability due to smaller scale, and exits of farms from the small-scale sector. (Gonçalves et al. 2008; Camilo Neto et al. 2012; Novo et al. 2013). Previous research thus suggests that low productivity due to limited adoption of technology in dairy farming is a relevant issue. The linkage between technology use and dynamic price behavior has not been sufficiently well explored. According to Adelaja (1991), economists have tend to ignore the effects of price changes on farm population, herd size, and the impact of heterogeneity in the short and long-term output responsiveness of dairy farms. However, note that Pagel (2005) using a SD model, examined the impact of policy changes on farm structure and responsiveness, accounting specifically for farm productivity characteristics and Nicholson & Stephenson (2015) analyzed the origins of price cycles in the US dairy industry and hypothesized that their causes are related to bounded rationality of the supply chain managers, with limited supply chain coordination.

Previous work by Souza (2000) and Gomes et al. (2003), examined the origins of price oscillations in Brazil using econometric models, indicating that they are due to the relative magnitudes of supply and demand elasticities. According to these authors, production systems with different technologic profiles – indicated by the herd genetic composition – show distinct response conditions to the market stimuli. They found higher supply-price elasticity in farms with Holstein breed followed by crossbred system by Zebu x Holstein and lower values for pure Zebu breed system. These previously-developed econometric models have not accurately represented the dynamic behavior of milk prices in Brazil.

Considering that supply and demand conditions are determined dynamically and have feedback loops by the price levels, it is possible to better understand the propagation pattern of shocks using methods that are capable to incorporate these characteristics and, further, considering delays between the actions and effects.

Thus, our objective is to assess how increased use of higher-productivity technology in milk production systems in Brazil would influence the oscillatory pattern of the milk prices over time. Our hypothesis is that more widespread adoption of technology will reduce the amplitude period and persistence of milk price oscillations. To achieve this objective, we develop a SD model and calibrate it to the Brazilian milk market context. We demonstrate that the SD model provides relevant insights about the relationship between technology use and the behavior of milk price in Brazil as suggested by Olaya (2015).

2. Theoretical Background on Oscillations in Agricultural Systems

The analysis of oscillatory behavior in production and prices in agriculture has a long history, dating back at least to the Cobweb model proposed by Kaldor (1934). Since its publication, many authors made contributions and empirical observations in the sense to better understand the mechanisms that causes price fluctuations mainly in the commodities markets (Akerman 1957; Arango & Moxnes 2012).

The Cobweb model differs from the static equilibrium analysis of a single competitive market due to an information delay in the supply response, because production decisions are made by farmers using the most-recently-observed (previous period's) price. From an initial equilibrium an exogenous shock results in price oscillations that assume three stylized forms. A "continuous fluctuation" behavior occurs when the demand and supply slopes (elasticity) have the same value. In this case the price oscillates in a constant pattern over time without an equilibrium being reached. A "divergent fluctuation" behavior occurs when the supply elasticity is bigger than the demand elasticity, and the price fluctuations amplify indefinitely to the limit when prices reach zero and production is abandoned or when the productive resources are exhausted. A third behavior, "convergent fluctuation" occurs when the supply elasticity is smaller than the demand and by consequence the oscillations tend to dissipate over time with prices converging to a new equilibrium state (Ezekiel 1938).

Behaviors differing from these three, including chaotic movements, can be produced introducing adaptive expectations, non-linearity of supply and demand functions (Hommes 1994) and other delays. Recent studies point to the importance of agent heterogeneity in the elasticity definition of the Cobweb model (Colucci & Valori 2011). The work of Meadows (1970) was one of the first applications of SD to examine price and production cycles that incorporated extensions to the basic cobweb, and it correlated technological parameters and biological delays with price responsiveness of production systems. Since then SD models have been widely used to model the price behavior in many markets including dairy (Liehr et al. 2001; Smith & van Ackere 2002; Ghaffarzadegan & Tajrishi 2010; Nicholson & Stephenson 2014; Rooney et al. 2015). Specifically for dairy supply chains Nicholson & Stephenson (2014) assessed quantitatively the impact of the Margin Protection Program for Dairy in US using a conceptual analysis and an empirical SD commodity model. Their findings suggest that SD modeling can help to inform public policies affecting the dairy sector.

From the point of view of SD, the oscillatory behavior observed in the Cobweb model is derived from a single structure composed by two balancing loops, one reinforcing loop and one delay. One can note that exogenous shocks in price will affect the productions systems (supply) and the demand with a delay. In sequence, the imbalance will be perceived by the price makers considering the adaptative expectations and transmited to the supply and demand quantities – considering the values of the elasticities – backing to form a new balance between them (Figure 1).

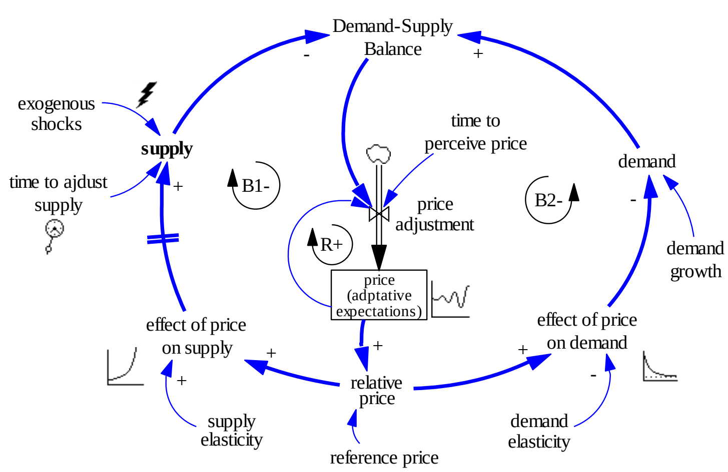


Figure 1 – Cobweb model represented by a causal-loop diagram.

3. Model Structure and Assumptions

The model to assess the role of technology on milk price behavior in Brazil builds on generic commodity cycles model such as Meadows (1970), Sterman (2000), and models specific to dairy markets, such as Conrad (2004) and Nicholson & Stephenson (2014). The supply components of the model include a detailed aging chain for dairy cattle (Figure 2) that is connected with the demand side (Figure 3) through the Dairy industry inventory and coverage. In both sides (supply and demand) the model is presented in a simplified view with only the main structures aiming to facilitate its explication[2].

The supply side comprises a stock and flow structure (aging chain) for a single, dairy farm with the herd age and sex composition determined by: calving interval, gestation time, fraction of female births, time to weaning, time to first breeding, culling rate and lactation period. These indicators are influenced by the nonlinear effects (table functions) of forage quality, use of concentrated ration and genetic gains which depends on economic variables, i.e., milk price, costs, expected profit and capital stock (bottom part of Figure 2). The desired herd size is limited by the land availability, stocking rate, beef price over milk price and investment decisions. Land is considered a scarce resource and therefore, as a premise, the possibility of buying or rent new areas for milk production was not modeled.

The total milk production of each farm is obtained by multiplying the number of lactating cows by the respective average productivity. As the other indicators, the cows' productivity is also affected by ration quantity, quantity and quality of forage, genetic and rainfall regime (top of Figure 2). Total milk production for the country is determined by multiplying the milk production per farm times the number of farms. The initial total number of dairy farms is exogenously set, however it follows a long-term trend reduction as reported by Brazilian official statistical database (IBGE).

[2] The full version of the model and all equations can be seen in the supplementary material or directly with the first author.

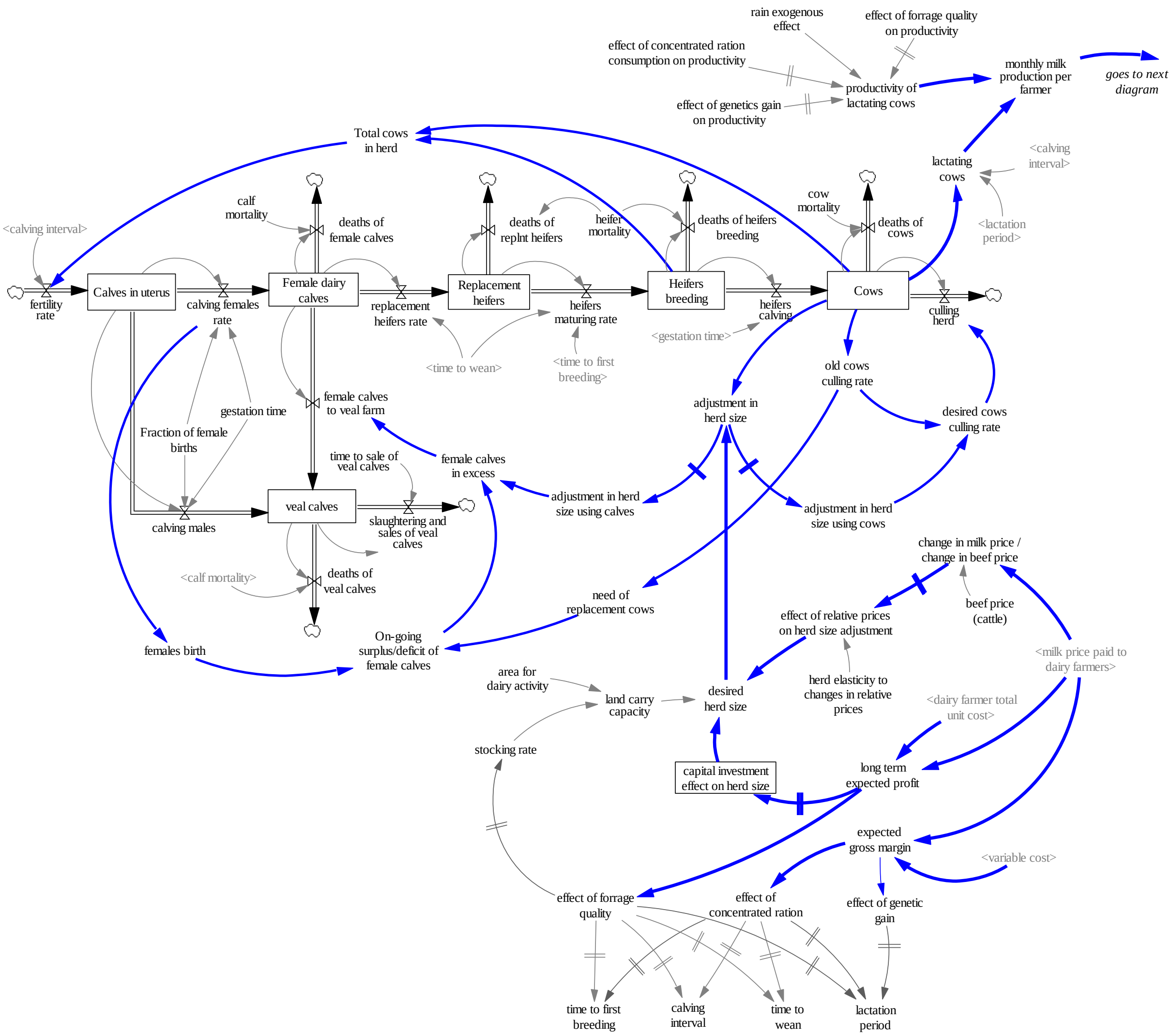


Figure 2 – Simplified view of the supply structure.

Although milk is a highly perishable product for which limited inventories are held (most inventories are held as dairy products further up the supply chain), we simplify the structure of supply and demand by using milk equivalents rather than the large number of dairy products that can be made from milk. The inventory of milk equivalents and its coverage are assumed to influence milk price formation (Figure 3). Although in many situations, farm milk prices are determined by short-term supply and demand balance for milk, we assume that the farm milk price also is influenced by the dairy farmers production cost (delayed by 15 months) and based on adaptive expectations. The model parameter values related to the responsiveness of prices inventory coverage and impact of production costs were specified through calibration (discussed further in the Results section and Table 2).

In the model, the price paid to dairy farmers represents a reference value for the whole supply chain (wholesale and retail price). Based on the observation that the largest use of farm milk is used for fluid milk consumption in Brazil milk and following the suggestion of Azevedo & Politi (2008), the price at consumer level was modeled using the fixed mark-up principle (fixed percentage) that represents the market power of processing and retail sectors. The main drivers of demand are population growth and per capita income (both exogenous; Figure 3).

Thus, fluid milk consumption is determined by the retail price level, income, and price elasticity.

Imports and exports of milk and dairy products are ignored, given that these comprise 2.6% and 0.3% of total production respectively (FAO 2013).

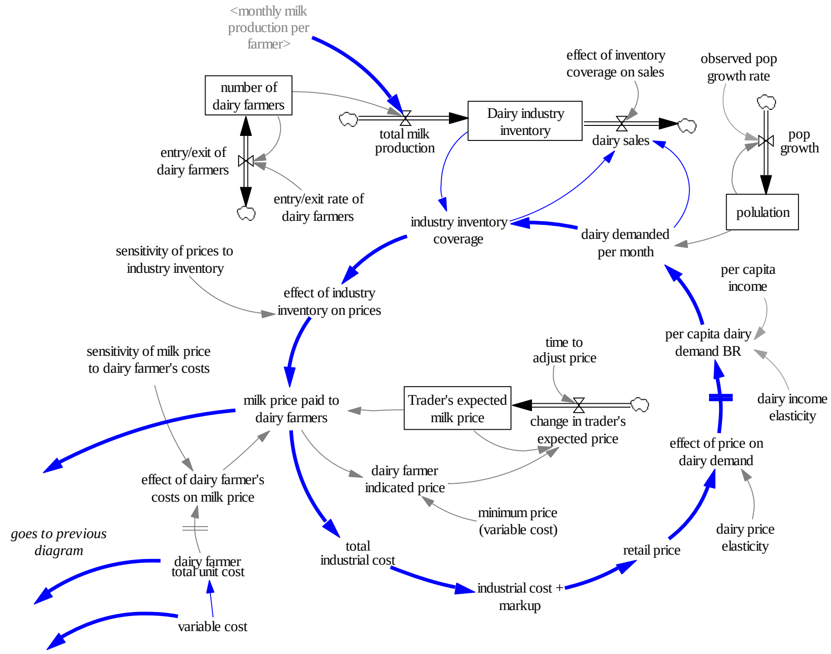


Figure 3 – Simplified structure of demand and milk price formation.

3.1. Tests and model boundaries

By definition all simulation models are an abstraction of the reality and therefore should be fully evaluated to insure that they are consistent with their stated purpose. The main tests recommended by Sterman (2000) were performed to assess model adequacy: a) boundary adequacy, b) structure assessment, c) parameter assessment, d) extreme conditions, e) sensitivity analysis and f) behavior reproduction. Dimensional consistency was maintained and integration error was also assessed. The Euler integration method that was used is recommended for most situations in which series discontinuities tests (pulse/step functions) are required and when high accuracy in the simulation results is not needed. The time unit was "month" and the time horizon 196 months. The time step was 0.125 indicating that every month the model was run 8 times (1/0.125), however the results were recorded and exhibited once per month. The simulations were performed with Vensim® DSS 5.5 software.

3.2. Data Sources

The state of Minas Gerais (MG) was used as a proxy for the whole country, since it has representativeness for several levels of milk production densities in its region (Zoccal et al. 2007), is the largest national milk producer (30%), has technological heterogeneity (Simões et al. 2015), and has a strong commercial linkage with other states (Carvalho et al. 2014; Fernandes et al. 2010).

Six experts in dairy farming were asked to describe the main technical parameters for three types of production systems (Extensive, Semi-confined and Confined) and three intensities of technology use (High, Medium and Low), resulting in nine technological profiles. The experts' opinions were prepared independently of each other and the responses were later consolidated.

After analyzing the data and eliminating discrepant values, three profiles were retained: High, Medium and Low technological production systems (Table 1). This division found is consistent with the traditional classifications observed in the literature (Figueiredo & Gomes 2009).

Table 1 – The three technological profiles of milk production systems estimated by specialists.

Parameters	Technological profile of milk production systems		
	Low	Medium	High
Stocking rate (head/ha)	1.20	1.80	3.34
Cows culling rate (% per month)	1.17	1.48	1.73
Calves mortality (% per month)	1.12	0.83	0.53
Heifers mortality (% per mont)	0.76	0.55	0.34
Cows mortality (% per month)	0.80	0.58	0.45
Fraction of female births (%)	50.0	53.0	59.0
Cows' productivity (L/cow/day)	12.0	17.0	24.0
Cows' ration consumption (Kg/head/day)	3.56	5.33	7.97
Genetics*	2.33	3.17	4.00
Time to first breeding (month)	26.6	22.4	19.3
Time to wean (month)	4.8	3.5	2.9
Calvin interval (month)	15.8	14.5	13.7
Lactation period (month)	8.6	9.6	10.6
Fraction of adjustment using female calves (%)	39.0	30.0	25.0
Ration cost per liter of milk (R$/liter)**	0.13	0.21	0.28
Variable cost (R$/liter)**	0.49	0.63	0.73
Fixed cost (R$/liter)**	0.74	0.42	0.21
Total cost (R$/liter)**	1.23	1.05	0.94

* Categorical variable that represents the herds' genetic pattern: 1= Undefined breed ; 2=1/2Holsteins/Zebu; 3=3/4 HZ; 4=7/8 HZ; 5=H100%. ** The production cost were adjusted and deflated according to the values presented in the dairy cattle breeding diagnosis of Minas Gerais (Gomes 2006).
Source: Research data.

Secondary data of time series – from January 2000 to April 2016 – were collected from Brazilian official database: population growth, income (GDP), per capita milk consumption, inflation index, number of dairy farmers, milk production (IBGE), price paid to dairy farmers, beef price, ration price (CEPEA-ESALQ-USP) and rainfall (INMET). The price and income demand elasticities were obtained in the available literature (Hoffmann 2007; Carvalho et al. 2008).

4. Calibration Process

Some parameters of the model were found through a calibration process using as reference the observed time series of the milk price paid to dairy farmers in Minas Gerais (Table 2)

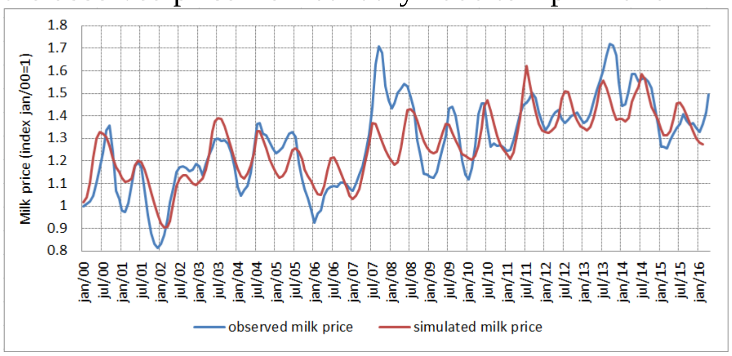
Table 2 – Calibrated parameters using the software Vensim.

Parameters	Technological profile of milk production systems		
	Low	Medium	High
Herd elasticity related to relative prices*	0.35	0.25	0.10
Sensitivity of investment to expected profit*	0.25	0.50	0.75
Sensitivity of using concentrated ration to expected gross margin*	0.75	0.50	0.25
Sensitivity of prices to inventory coverage**		-0.22	
Sensitivity of milk price to dairy farmer's costs**		+0.25	
Entry/Exit rate of dairy farmers (% per month)**		-0.25	

*The calibration was performed to meet a value corresponding to a typical production system of MG and then extrapolated to the systems of Low, Medium and High technological level based on the experts' opinion. **Values used for all technological profiles.
Source: Research data.

The results of the calibration experiment considering two period lag reached a R^2 of 0.67 and a Pearson correlation index of 82% (Figure 4). One can note that the model reflects the seasonal effect of the prices that is highly determined by the rain regime, as well the tendency over the years. The difference observed between the two lines concerns the intrinsic error of the model caused by the omitted variables.

Figure 4 – Comparison of the simulated time series of the milk price paid to dairy farmers and the observed price from January 2000 to April 2016 in Minas Gerais.



Source: Research data.

5. Results

After the calibration process the model was set to initialize in dynamic equilibrium by removing all exogenous effects (per capita income, population growth, rain fall, beef price, ration price) and then simulations with controlled exogenous shocks were performed using the Step and Pulse functions[3]. On the supply side were made shocks on the concentrated ration cost and on the rainfall conditions. On the demand side the shocks were performed on the population per capita income. It is important to note two points regarding this experimental design. First, initialization in dynamic equilibrium and the elimination of other exogenous factors implies that the model experiments will not replicate the observed behavior of milk prices, which show seasonal fluctuations and no longer-term cyclical pattern. Second, the experiments are largely hypothetical, because each assumes that all farms would have the production technology (not the existing distribution of technologies actually used), and the objective is to observe differences in these hypothetical responses, not to replicate the existing farm structure and observed behavior.

The first simulation was performed using the parameters of a typical technological profile of milk production systems of Minas Gerais state and assessed, separately, the impact of a 10% increase on per capita income and on production cost and a 10% reduction on rainfall regime during 4 months (Figure 5). It is noted that the increase on population income causes an impact on milk price more quickly and in greater magnitude than the increase of production cost. On the other hand, the cost shock has a more pronounced oscillatory effect and the prices are stabilized

[3] As is familiar to many SD modelers, the STEP function causes an increase in the value of a variable at any given moment and keeps it at this new level until the end of the simulation. The PULSE function causes an increase in the value of a variable during a given period, which then returns to the original value.

at a higher level. It is also noted that a rainfall regime lower than the equilibrium condition causes a price oscillation of greater amplitude, frequency and persistence over the years. Seeking to assess the opposite scenario the second simulation was performed considering a reduction of 10% on population income, production cost and an increase of 10% on rainfall over the normal condition(Figure 6). Similarly, shocks on income and cost lead to long-term price oscillations. The reduction of population income causes oscillation of greater frequency and amplitude than shocks of reduction of production costs. Comparing the two graphs, it can be seen that the population income reduction effect generates greater price volatility than when there is an increase in income, signaling the need for income maintenance policies in order to stabilize markets.

Figure 5 – Effect of increased income, production costs and the scarcity of rainfall on milk price paid to farmers.

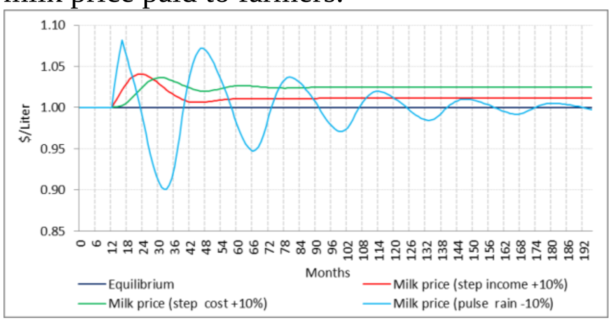
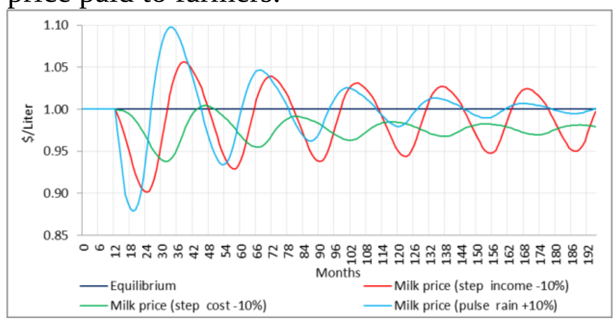


Figure 6 – Effect of reduction income, production cost and excessive rainfall on milk price paid to farmers.



Source: Research data.

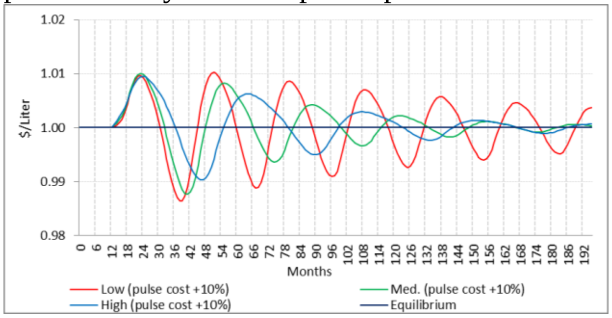
In the simulation presented in Figure 7, each line represents a set of milk producers with different technological profile: Low, Medium and High. For these scenarios, it is assumed that all milk producers in a given region (state or country) are represented by one of these technological profiles. It is observed that the higher the technological level, the lower the amplitude, frequency and persistence of the price oscillations when shocks of increase on production costs (+ 10%) are performed. This result shows that the increase of assets specificities, especially the technological, can contribute to reduce the instability of price and, consequently, increase the competitiveness of the dairy supply chain.

Similarly, the reduction of the income level of the population can lead the prices to an oscillatory behavior. However, in Figure 8, it is verified that when production systems uses more technology the oscillatory pattern has smaller amplitude and is smoothed over time. This evidence indicates that the technological improvements do not only brings efficiency benefits to the productive sector but also contributes to the society welfare.

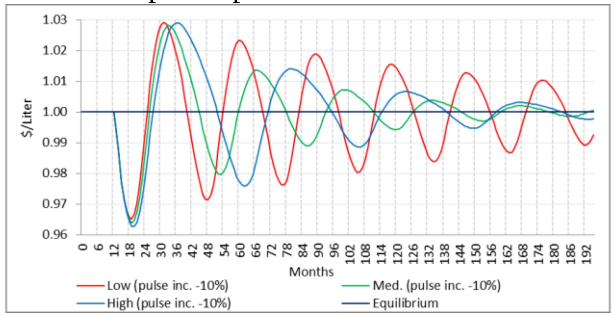
Figure 7 – Effect of increased cost of different

Figure 8 – Effect of reduction population

production systems on prices paid to farmers.



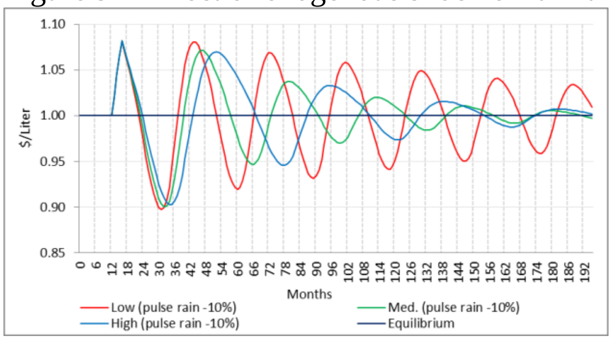
income on prices paid to farmers.



Standardized prices at the beginning of the simulation. Pulse of 10% during 3 months.
Source: Research data.

The last exogenous shock was applied in order to test the model under rainfall scarcity conditions, since this is a relevant factor in Brazilian milk production conditions. As expected, the system with high technology causes lower price volatility over time, which can be attributed to adoption of more efficient food conservation practices and/or irrigation investments (Figure 9).

Figure 9 – Effect of exogenous shock of rainfall reduction on prices paid to farmers.



6. Discussion

Although the Brazilian milk price shows a well-defined seasonal behavior and is marked by climatic conditions (Alves et al. 2015), the results found by the simulation model reflect longer-term oscillations, which are not present in the observed data during 2000 to 2016. The pattern of longer-term oscillations is in agreement with the results of Chavas & Kraus (1990) and Tauer (1998) who state that the herd composition and milk production responses are inelastic in short-term. According to these authors elastics responses in milk production only can be observed at least after 7 years of adjusts in variable related to herd feeding costs and to beef price. Corroborating this argument, Adelaja (1991) points out that differences in output responsiveness imply differentials in the impacts of price changes and price support programs on dairy revenues in US. He also states that economic efficiency analyzes may be "short-sighted" by not considering the different time horizons necessary for exogenous shocks to be incorporated into production systems and, consequently, to the prices practiced. Therefore, the simulations carried out in this study are in line with the theoretical and empirical evidences that short and long-term responses of milk production vary significantly with the specialization level and capital use.

The mathematical model of milk supply proposed by Bozic et al. (2012) concludes that short-term price volatility arises on the supply side primarily from changes in cow productivity, while long-term price changes come from changes in herd structure. According to this author, the desirable effects provided by support programs for farmers in short-term can lead to unwanted consequences in the medium and long term, which is consistent with basic premises of System Dynamics.

The studies of Munshi & Parikh (1994) e Bhattacharya et al. (2016) attribute the price oscillations to the magnitudes of short and long-term elasticity (and the very nature of differences between the two suggests that formal modeling of the underlying delay structures can provide useful insights) further emphasizes that models with an endogenous herd structure (such as the one described herein) may necessary. In general, the model suggests a hypothetical reduction in the amplitude and duration price fluctuations results from technological innovations, which may improve commercial relationships between farmers with dairy processors (confirming the findings of Marques et al. (2015)) and decrease industry-wide adjustment costs in response to price variations.

In 2001, the milk price paid to farmers in Brazil reached its lowest level in the last two decades. At the time, experts pointed out the most diverse exogenous sources as cause of such a decline: energy blackouts, milk imports and a supposed excessive market power of the dairies (Scalco & Braga 2014). In fact, these exogenous sources may have impacted the milk price in this period, however, there are scientific evidences indicating that such price fall was determined by the differences between supply and demand elasticity. According to Gomes et al. (2003), the increasing number of farms with high technology level in Brazil combined with a low demand elasticity can explains the price fall observed in that period. In this work, Gomes concluded that 50% of cow productivity is adjusted in up to one year after any price incentive, while the herd is adjusted in periods longer than this. The work of Souza (2000) is also important in this sense because it correlates the elasticity of milk supply with different production systems based on the herd genetic specialization. Considering several incentives on supply and demand side, production systems with more specialized herd showed higher elasticity than less specialized herds.

When the results of these last two authors are compared with the results found in the simulations of this work, it is noted that the three simulated systems have a similar behavior up to one year after the exogenous shocks. However, the long-term dynamic analysis is counterintuitive, since it presents a smoothed effect of the oscillations correlated with the increase of the technological level. The results of the simulation are supported by Ferreira & Gomes (2004) in the sense that the greater the technology adopted in the production process the less flexible will be the herd management, and therefore these production systems will be more resistant to changes due to price oscillations.

7. Conclusion

A simulation model using System Dynamics was developed to assess the impact of technological level in dairy production systems on the pattern of price oscillations for hypothetical scenarios. The results suggest but do not indicate definitively that technical and economic efficiency gains may reduce the amplitude and duration of milk prices in response to exogenous shocks to both supply and demand. The underlying theoretical model and results of previous studies indicate that price oscillations are strongly influenced by differences between the magnitudes of the supply and demand elasticity. Thus our main contribution to understanding such oscillations relies on observation of long-term behavior, indicating that policies which promote technology adoption in productive sector might contribute to reduce amplitude and duration of oscillations, which might also facilitate the implementation of private strategies promoting greater market integration. A more realistic extension of our analysis would better replicate the existing pattern of prices, and to this end it may be desirable to combine the SD methodology with other techniques such as Social Network Analysis in order to identify the best forms of diffusion of technological innovations in regionalized contexts and Agent Based Modeling to address the heterogeneity of farmers groups and their relationship with dairy processors.

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