A SYSTEM DYNAMICS MODEL FOR THE WORLD COFFEE MARKET

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ABSTRACT

Commodity prices cycles have a negative effect in developing countries. This paper applies system dynamics to study the long term cyclical behavior of coffee price. The model is based in Meadows (1970) and Deaton and Laroque (1996, 2003). The model includes the price dynamics, investments, capacity, and demand. Our model is the first stages and not fully calibrated. Nevertheless, the model provides a better understanding of the commodity cycles, focusing on the internal structure of the system. The model replicates the reference mode, thus, coffee price exhibits cyclical behavior in the long term. In particular, we have founded very difficult the estimation of investment functions; therefore, future work will be focus on validation and use of laboratory experiments to estimate investment function with coffee farmers.

KEY WORDS: *Commodity cycles, coffee market, system dynamics, investment, laboratory experiments.*

Introduction

It is well known that commodity markets fluctuate with certain regularities, these fluctuations show cyclical behavior (Bélair and Mackey, 1989; Spraos, 1990; Cuddington & Urzua, 1989; Cashin *et al* 2002, Cashin & Patillo, 2000; Deaton & Laroque,1992, 1996, and 2003), commodity prices are extremely volatile (Deaton & Laroque, 1992) and them have significant negative effects for consumers, producers and developing countries specially in Africa and Latin America (Deaton, 1999; Akiyama *et* *al* 2001; Akiyama *et al* 2003). For many producing countries, one or two commodities were especially important in terms of employment, export income and government revenues (which can account for over 75% of their total export earnings) (Akiyama *et al* 2003; ICO, 2009) which means that if a commodity price fall deeply it prompts economy crisis in many countries.

In spite of this, and that trade of commodities represent the 25% of total world trade (Cashin and Patillo, 2000) most modern introductory textbooks in economics either ignore commodity cycles (ex. Mankiw, 2004; Sloman, 2002; Samuelson & Nordhaus, 2001; and Case & Fair, 1996) or they deal with the phenomenon using the highly simplified cobweb model (e.x. Lipsey & Chrystal, 2003). With few exceptions, the same is the case in journal articles dealing with commodity cycles. Consistent with these observations, several authors claim that the behavior of the prices of primary commodities remains poorly understood (Cashin *et al* 2002; Deaton & Laroque, 1996 and 2003).

Figure 1 gives the annual coffee prices (US$ cents per pound); it shows an index calculated by ICO from 1900 to 2008. The series shows no obvious trend, although there are several sharp peaks, most notably in late 1970´s, 1980´s and 1990´s. After each peak the prices fall deeply down and then beginning to rise again. This behavior seems to be happening during this century.

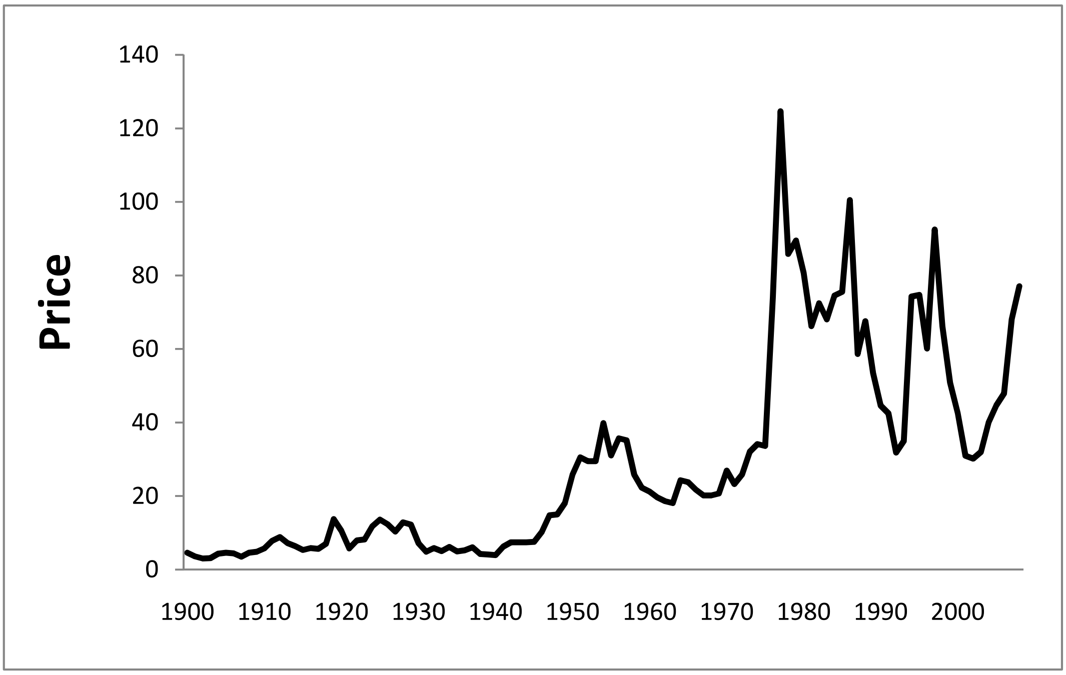


FIGURE 1. Annual coffee prices 1900-2008 – Source: ICO International Coffee Organization and Deaton and Laroque 2003

Many authors recognize the existence of cycles at the coffee price (Talbot, 2004; Mehta and Chavas, 2004), these cycles are recognizing by Nestor Osorio, executive director of the international coffee organization ICO (Capdevil, 2007). Mehta and Chavas (2004) believe that the fact that coffee trees take four to five years to become productive in combination with the view that coffee prices are nearly impossible to predict at the five year horizon and that farmers therefore rely on adaptive expectations when investing, this suggests the potential for a coffee price cycle.

Stockholding is a way that we can use to mitigate weakly the impact of Commodity price variability arises from supply and demand shocks (more from the former than the latter for agricultural commodities) which are amplified by short term demand and supply inelasticity (Gilbert,2004). There have been many works trying to model how the inventory-moderated process affects the commodity price cycles. Samuelson (1957) showed the effect of storage on grain prices, Gustafson (1958) studied the properties of optimal storage; Muth (1961) introduced the assumption of rational expectations.

A system dynamics model was developed by Meadows (1970) the model expands the Cobweb market, changing the dynamics in the production system. Whole the Cobweb model had one production lag; Meadows model has investment, construction delays and capacity. Meadows assumed that subjects changes their expectations slowing; he used the “adaptive expectation” model developed by Nerlove (1958) in order to forecast producers’ price and consumption. Meadows model was published on a book form (Meadows, 1970), what limited its diffusion.

The first attempt to explain commodity prices in terms of simple theory based on competitive storage, using rational expectations equilibrium in a simple non-dynamic model of supply and demand with a single state variable “amount on hand” defined as production plus lagged carryover was made by Deaton and Laroque (1992). The model uses an i.i.d process for the harvest, this model seems like a very poor candidate for explanation of data Deaton and Laroque (1995), appears to be incapable of generating the high degree of serial correlation of most commodity prices Deaton and Laroque (2003).

Assuming that harvest are autocorrelated such Deaton and Laroque (1996), does not appear to contribute much to replicate the higher levels of autocorrelation of prices displays in most of the actual commodities prices. Williams and Wright (1991) developed a more complicated dynamics model involving two or three state variables; they used numerical methods to approximate to the rational expectations equilibrium.

The stockholding models capture part of the reason for commodity price autocorrelation but that, by itself, it is insufficient. Developing models that are able to represent supply and demand shocks will help us to understand better commodity price cycles. A successful model should be able to answer question about over-investment and permitting the evaluation of policies. Gilbert (2004) recognize that the key to future developments maybe a better understanding of investment decisions.

The paper proceeds as follows. In the next section, we explain the world coffee market and the history and role of the International Coffee Organization ICO. Section 2 we explain each part of the model and the assumptions made for simulation. Section 3 shows how we calculated parameters and functions used at the model. Section 4 provides results from different scenarios proposed to understand the system and trying to validate the model. Section 5 present a brief discussion about how we may get models that can replicate the characteristics of commodity price cycles.

1. The World Coffee Market

1.1 Before Coffee Market Liberalization

Developing country governments regulated coffee marketing and pricing for years, not only because coffee was very important as source of export earnings and foreign exchange but also for institutional and political reasons; for countries like Brazil and Colombia their objective was to raise world prices. In this period, the market was under the influence of The International Coffee Organization (ICO).

1.1.1 History and Role of ICO in the World Coffee Market

During the Second World War from 1939 to 1945, demand fell and prices were low. However, after the war, demand increased and supplies were inadequate to satisfy this rising demand. Between 1950 and 1953 stocks reached levels below the minimum needs for normal trading purposes, a situation which was exacerbated by the outbreak of the Korean War and a serious drought in Brazil, which was followed by a frost. Prices rose to unprecedented heights in 1953. This gave rise to a substantial increase in planting throughout the world and over-production followed. Stocks increased and, in the second half of the 1950s and early 1960s, prices fell drastically (ICO, 2009).

Therefore, The International Coffee Organization (ICO) was created in 1963 to raise and stabilize the world coffee prices through export quotas. Most coffee-producing and importing countries were members. The ICO had had an important impact on the world coffee market until its collapse in 1989.

The first two ICA (1962 and 1968) created a quota system whereby supplies of coffee in excess of consumer requirements were withheld from the market and policies were initiated to limit supplies of coffee and promotion activities instituted to increase consumption, these agreements were successful throughout the years 1963 to 1972. The third ICA (1976) had as principal features that it allowed for the suspension of quotas if prices were high and their reintroduction if prices became too low.

The high prices of coffee owing to a severe drought in Brazil (which affect coffee production significantly) make that the capacity of production of countries nonmembers increase and the inability for members of ICO to agree a way to control export to nonmembers and distribute quotas triggered the collapse of quota system in July 1989 (Akiyama et al, 2001).

Nowadays, ICO is the main intergovernmental organization for coffee, bringing together producing and consuming countries working together to resolve the problems of the world coffee and trying to improve standards of living in developing countries.

1.2 After Coffee Market Liberalization

In 1985 only 15 of the world´s 51 major coffee-producing countries had private marketing systems; at beginnings of 1990 these countries started to reform their market system. Economic problems in coffee-producing countries as result of very low coffee prices that followed the collapse of the ICO quota system in 1989 forced many governments to ask for financial assistance to international organizations but this assistance came with strings attached like some market reforms (Akiyama, 2001).

These market reforms in many countries transformed the regulated market into private marketing system triggering competition in all the coffee supply chain. Nowadays, coffee is traded down a complex line of intermediaries, ranging from local traders, exporters, international traders, roasters and retailers, who each capture a percentage of the retail value of coffee; hence, the link between producers and consumers is lost.

Most of the retail value of coffee is captured during the second stage of processing, which occurs outside of the producing countries. In fact, less than 30% of the $43 billion generated by world coffee sales remains in coffee producing countries. The remaining 70% is shared among multinational companies who control most of the international coffee supply chain (Oxfam, 2001).

A handful of multinationals, which often control the production of coffee from the farm-gate to the supermarket shelf combined with the fact that there is chronic oversupply of coffee on world markets, lack of coordination among producing countries and that the 70% of world´s coffee is produced by small producers (less than 10 ha) reinforces the power of buyers in the supply chain because they can pick and choose between suppliers is one of the main reasons of the growing gap between producer and consumer prices.

Different organizations have been created by growers to try to eliminate the huge gap in power negotiation between small farmer and big buyers (as the multinationals); the National Federation of Coffee Growers of Colombia is just one of many examples.

2. System Dynamics Model for the Coffee Market

Recent developments in social science suggest that simulation is a viable technique that can deal with complexities of this question in a more comprehensible way than more linear-like research methods (Berends and Romme 2001). System dynamics is a useful analysis tool for analyzing and studying the behavior of complex nonlinear dynamic systems by identifying the cause and effect relationships and the feedback control mechanism that creates the dynamics of such systems as commodity system.

Meadows model is our starting point. The basic idea is that the cycle originates in discrepancies between supply and demand; key elements in his model are the delays between the moments that the information is available and the moments that the information is used for decision making.

Figure 2 shows the iterations of the principal system variables such as production capacity, harvest, amount on hand, price, consumption, expected price, desired capacity production and investment. In Figure 2 we can see tree balancing loops B1, B2 and B3. In B1 and B2 the coffee price decreases when the harvest/the amount on hand increase, respectively. A higher coffee price reduces the consumption and increase the expected coffee price, a higher expected coffee price increase the level of desired production capacity and with this increment the coffee plantation increase. At B3, an increment in coffee price reduces the demand, a higher demand increase the coffee price.

There is a lag between the moment in which you invest in a new plantation and the moment, in which the first harvest is available, similar to Meadows (1970), we assumed that the delay is in the form of a pipe-line.

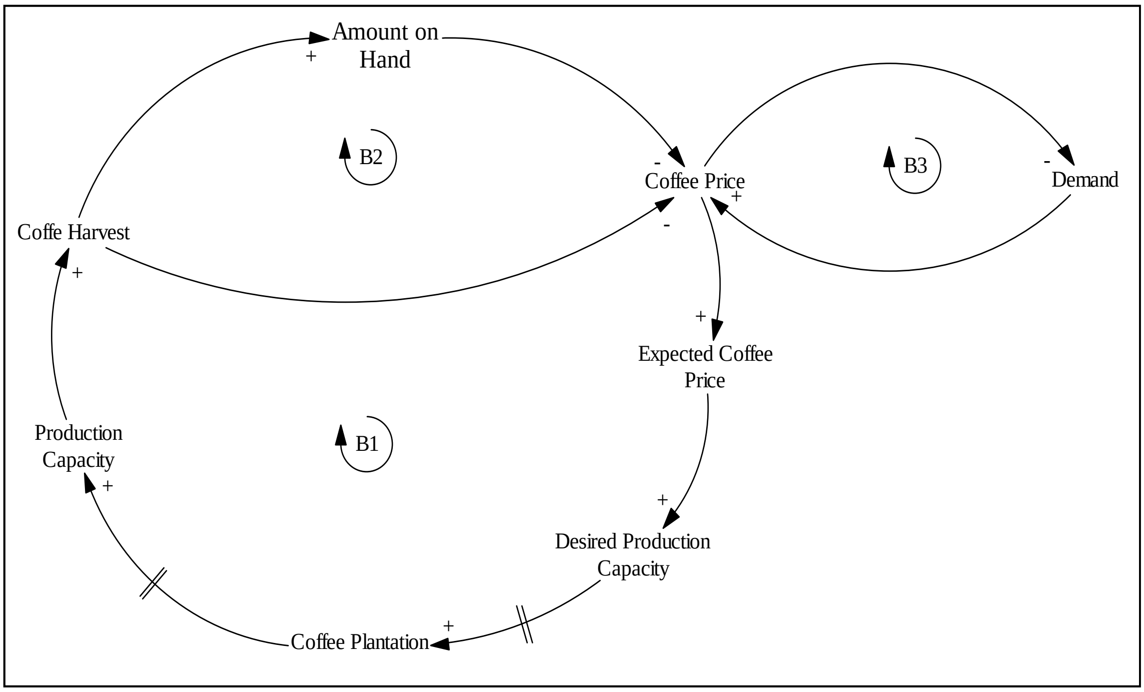


FIGURE 2. General casual diagram

2.1 Price

The price is set up based on the Deaton and Laroque model (1996), they use a logarithmic decreasing function at which the price depends of the level of the current harvest and amount on hand and there is only a unique price for a per of values of harvest and amount on hand.

Figure 3 shows the form of price function in term of availability or “amount on hand” and the harvest calculated by Deaton and Laroque (1996).

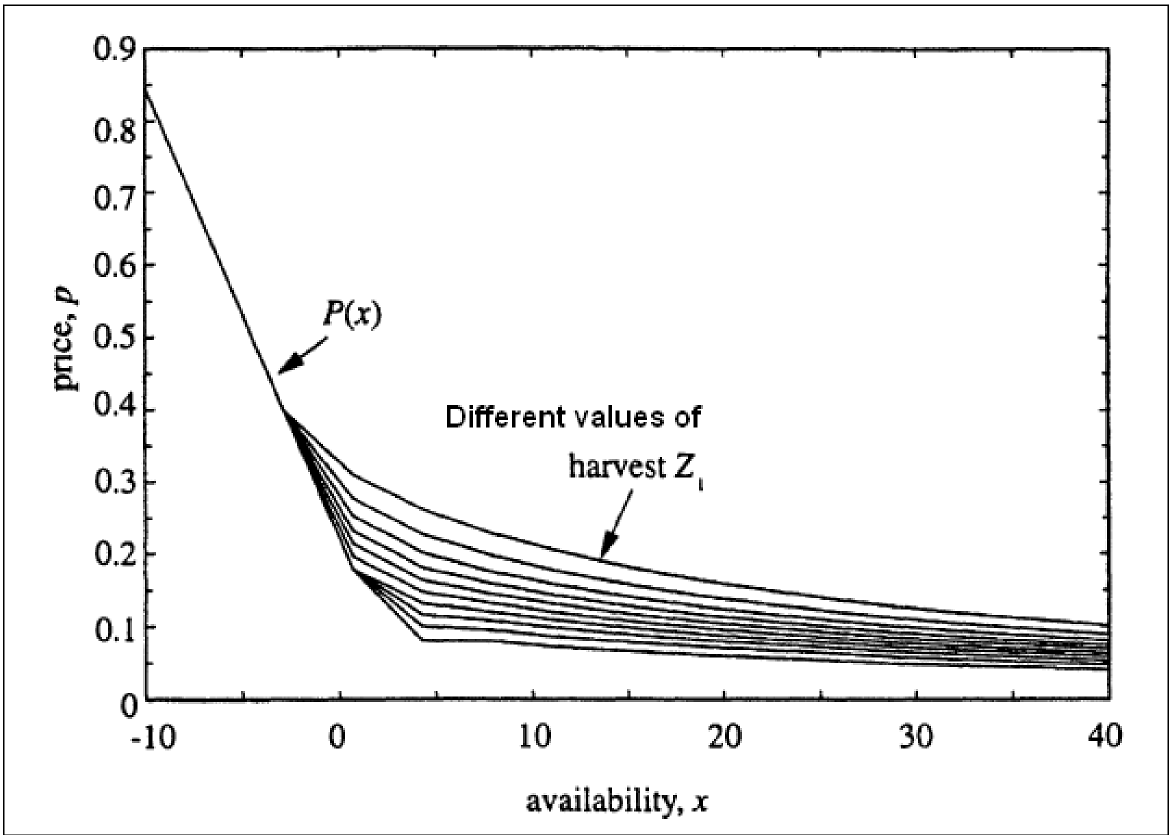


FIGURE 3. Price as function of availability and harvest – Adapted from Deaton and Laroque (1995)

2.2 Investment

The general view of economic theory shows that investment decisions reflect agents´ rationally formed expectations; decisions are made using all available information in an efficient manner (Scharfstein and Stein, 1990). Therefore, in this paper we use two different investment functions, one is the Meadows' investment function and the other is the flexible accelerator model of investment developed by Chenery (1952) and Koyck (1954).

2.2.1 Meadows Investment Function

In his model the producers are motivated to maximize profit, and their decisions to invest are guided by this principle. Producers use the expected price as an indicator of future profits, and this as an indicator of the desired capacity.

He used adaptive expectations to calculate the expected price; an adaptive expectation means that the producers not adjust their forecast instantaneously to the most recent market price. Put formally, the expected price at time t is defined as

$$P_t^* = P_{t-1}^* + \beta(P_{t-1} - P_{t-1}^*),\ 0 < \beta \le 1 \qquad (1)$$

Desired production capacity is an equilibrium concept that specifies the amount of capacity which would be maintained in the long- run if the price were to remain at its expected level. With each expected price there is associated a unique desired production capacity.

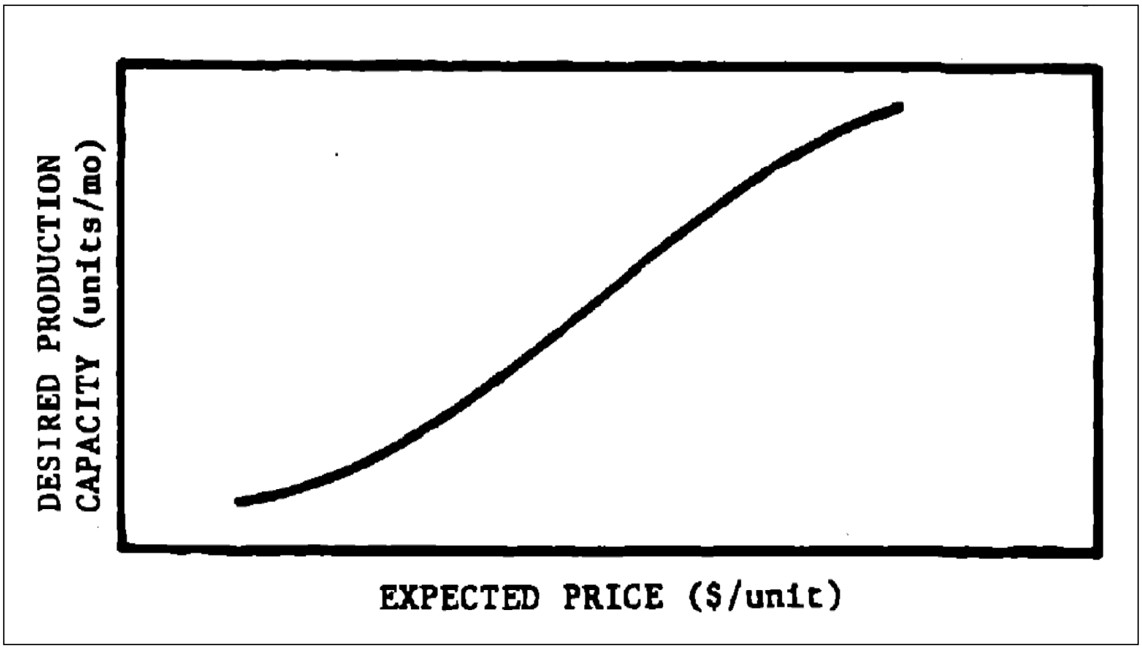


FIGURE 4. Expected price Vs desired production capacity – Source Meadows (1970)

Once the desired capacity production value is known we should estimate the capacity transfer initiation rate that depends of the desired capacity production, current capacity production, capacity being transferred and the capacity transfer initiation delay; this latter is the time period required by producers to eliminate the difference between actual and desired capacity.

2.2.2 Flexible Accelerator Model of Investment

This model pays attention on the time structure of the investment process. Changes in the desired capital are transformed into actual investment expenditures by a geometric distributed lag function.

Denoting the current level of capital by K and the desired level by K^+, capital is adjusted toward its desired level by a constant proportion of the difference between desired and current capital. Put formally, the investment at time t is defined as

$$K_t - K_{t-1} = (1-\lambda) * \left[K_t^+ - K_{t-1}\right] \qquad (2)$$

The flexible accelerator model provides an explanation of change in capital, but not of gross investment, but this model may be transformed into a complete theory of investment behavior by adding a specification of desired level of capital and a model of replacement investment (Jorgenson, 1971) this might be so difficult, especially if all the data is not available.

2.3 Production Capacity

The traditional econometrician models of commodity cycles do not have feedback over production capacity (ex. Deaton and Laroque 1992, 1996 and 2003); they generate the values of harvest by modeling the series of production.

Our model such as Meadows is a system dynamics model which permits the production capacity will be influenced by two reasons: investment in new plantation and the depreciation of the existing one, what is more realistic because the price has a significance influence on the production capacity.

We developed a system dynamic model which is convenient because the nature of the fluctuations in the commodity prices is a dynamic system, this fluctuations are occasioned by the lags between the moment that one invest and when the new production capacity is available.

2.3.1 Utilization Capacity

We assumed that the capacity utilization factor is fixed at 100% of the production capacity because the most of costs on the commodity production process are fixed ant these take place at the beginning of the investment, for example buying the land. Besides there are many penalties associated with the suspension of production, for example if there are not a continuously maintained of fields, they will erode, orchards may be infested, for these reasons.

2.4 Demand

The demand is formulated as a constant elasticity price. The demand function at time t is defined as

$$D_t = Exp((Ln(P_t / A)) / E) \quad (3)$$

Linear and iso-elastic functions are the most common functions used to represent demand functions, iso-elastic function has been widely used in commodity models such Williams and Wright (1991) and Deaton and Laroque (1992). The long-run consumption is a very minor factor in long-term commodity cycles (Meadows, 1970); therefore, we assume no difference between the long and short run dynamics of the function in the model.

The overall of the model is shown in the Figure 5. In the Forrester diagram shown in Figure 5 we see 3 stocks: inventory, which is affected by two flows (production and demand); capacity being transferred, which is affected by plantation and maturation;

and the last level is production capacity which is influenced by maturation and capacity depreciation.

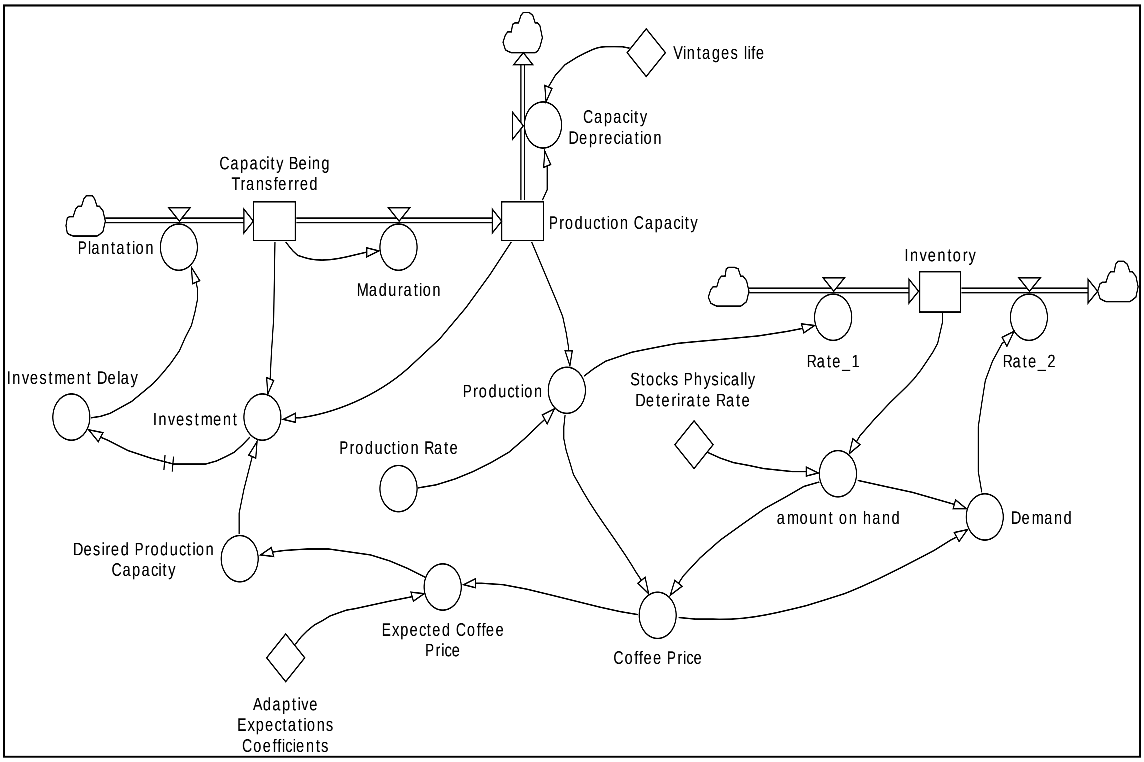


FIGURE 5. General stock and flow diagram

3. Parameter Estimation

This section shows how we estimated the functions parameters that we have used in the model.

3.1 Price

Table 1. Parameter estimation for the price function

	m1	m2	b
Coef.	-2,153062892	-295,4427549	1598,46723
Stand. Error	94,6956716	96,21203431	280,5557238
r2 - st.err y	0,607995143	14,16939499	-
F - degr.freed	15,50988803	20	-
ssreg-ssresid	6227,894858	4015,435085	-
t-observed	-0,022736656	-3,070746368	5,697503543
p-critical	0,982085655	0,006031627	1,41466E-05

For our case, this function was estimated by regression method with ICO International Coffee Organization information from 1977 to 1999. Put formally, the demand at time t is defined as

$$P_t = m_1 * \log(X_t) + m_2 * \log(Z_t) + b \quad (4)$$

At equation 4 X_t is the amount on hand at time t, Z_t is the harvest at time t and b as the intercept. Table 1 shows the coefficients values of m_1, m_2 and b; p-value is less than 0.05 for the parameters m_2 and b, these are different from zero, it means that we reject H_0; for m_1 we accept H_0. Table 1 also shows that the statistical R^2 is equal to 0.607 which means that the amount on hand and the harvest explain a 60% of the variability of the price.

3.2 Demand

The demand function is estimated by regression method with ICO International Coffee Organization information from 1977 to 1999.

Table 2. Parameter estimation for the demand function

	E (elasticity)	**A**
Coef.	-1,567809	3913013617
Stand. Error	0,463678	199,2254305
t-observed	-3,381246	4,1718451
p-critical	0,0028194	0,0004308

Table 2 shows the coefficient values of parameters A and E of equation (3); in which E represent the constant demand elasticity. We reject Ho for A and E, which means that both coefficient are significant different from zero because their p-value are less than 0.05.

4. Results and Model Testing

We run initial simulation in order to understand the model behavior. The model is not fully calibrated, therefore, the purpose of the following simulations is to understand the model and build confidence as part of the validation process (Barlas, 1996). Thus, we formulated different scenarios.

4.1 Base case

In this case we used the Meadows investment function, 0.5 as the coefficient of adaptive expectation and the lag of 3 years between farmers want a desired production capacity and the moment they invest.

At Figure 6 we can see that coffee price cyclicality behavior and this shows sustained oscillations around $200 - $400 per tons with an approximated period of 15 years; this behavior means that although the model is not fully calibrated the structure of de model captured the structure of the system.

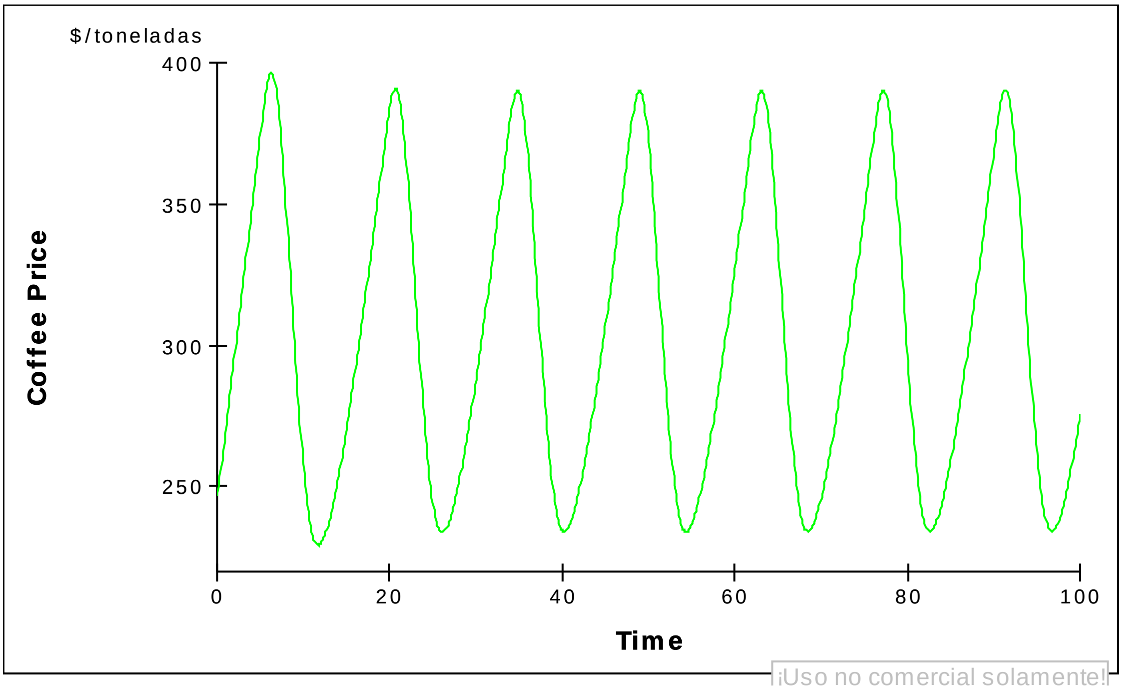


FIGURE 6. Simulated coffee prices- base case

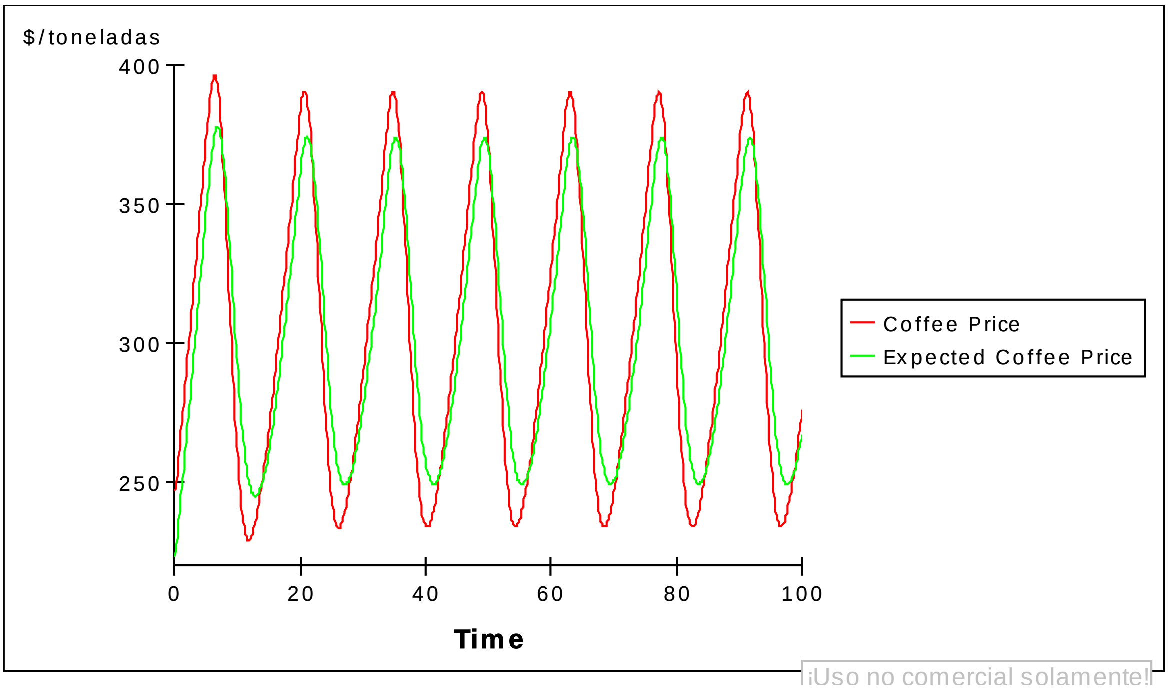


FIGURE 7. Expected coffee price - Base case

Figure 7 shows the expected coffee price behavior compared with coffee price. Both have the same period and sustained oscillations but the expected coffee price has smaller up and downward peaks due that in this case the farmers take two years for adjust their expected coffee price.

Figure 8 shows the production of coffee. It has cyclicality behavior with the same period of price, but the peaks are invert.

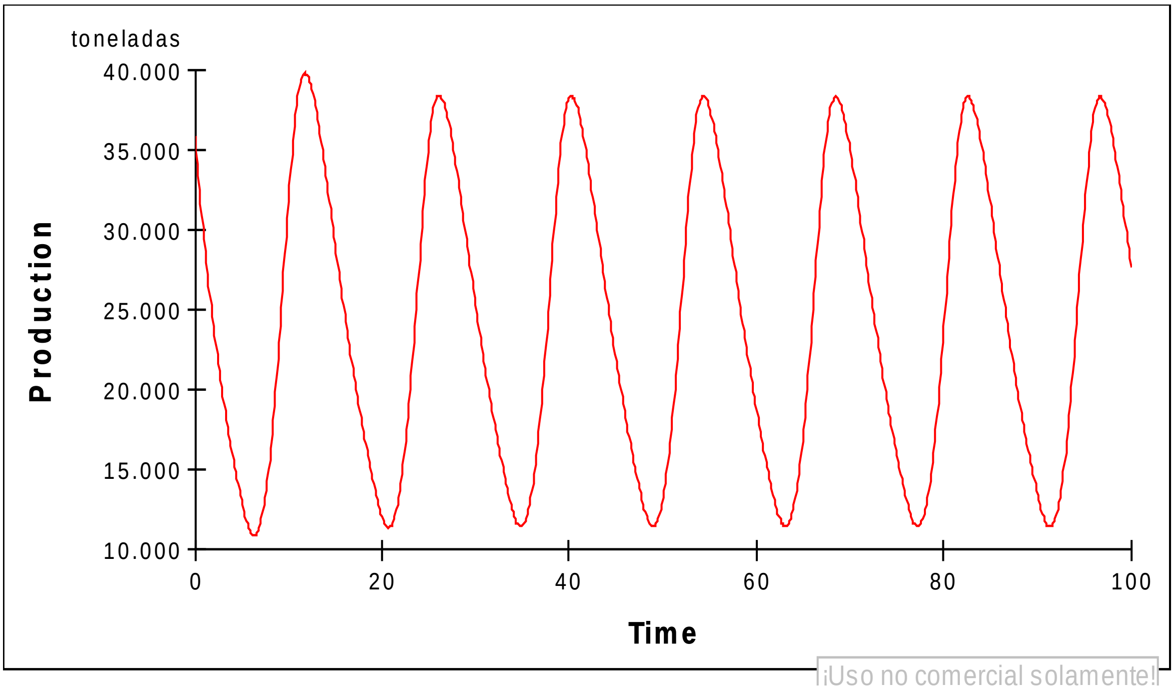


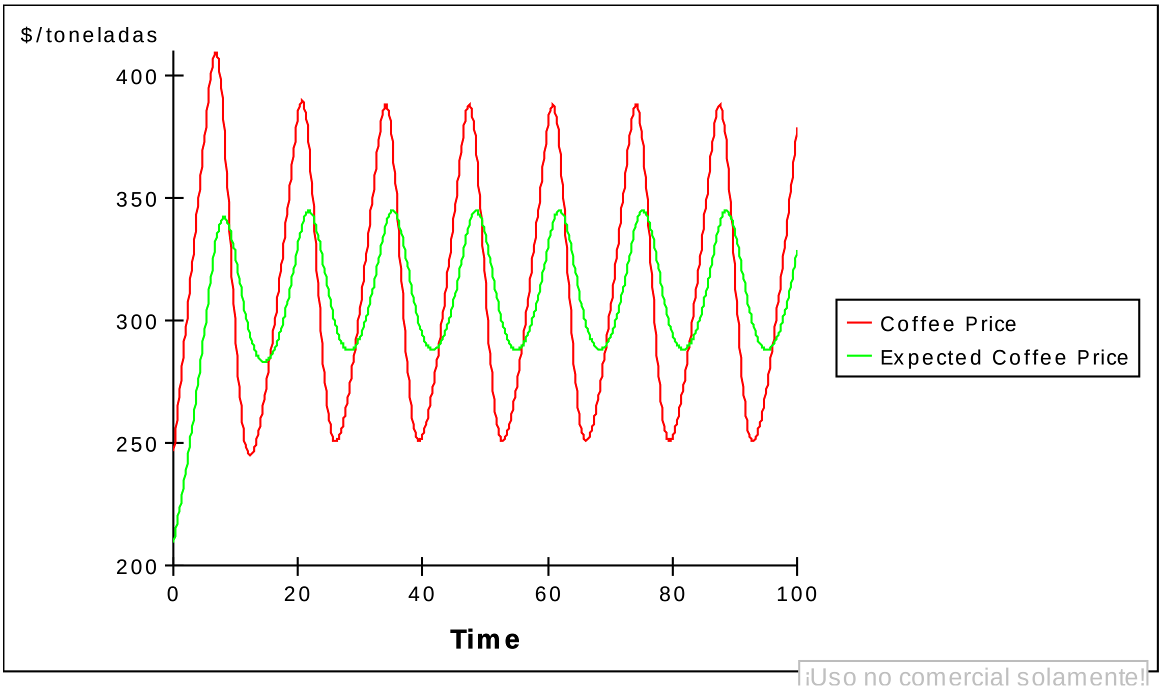
FIGURE 8. Coffee production - Base case

4.2 Simulation varying parameters

In this part we changed some assumed parameters such as coefficient of adaptive expectation, parameters in price formulation and delays to see how it will affect the behavior of the system.

4.2.1 Coefficient of adaptive expectation

At Figure 9 we see how changes the values of expected coffee price, its oscillations are smaller but the behavior is similar. This behavior was expected owing a smaller value of the coefficient of expectation means that farmers will take more time to adjust their expectations about coffee price, therefore, if expected price do not reach the level of up and down peaks the new investments are smaller or bigger respectively which results on coffee price oscillations smaller than in base case and its period is approximated of 14 years.



¡Uso no comercial solamente!

FIGURE 9. Coffee price and expected price - Coefficient of expectation 0.2

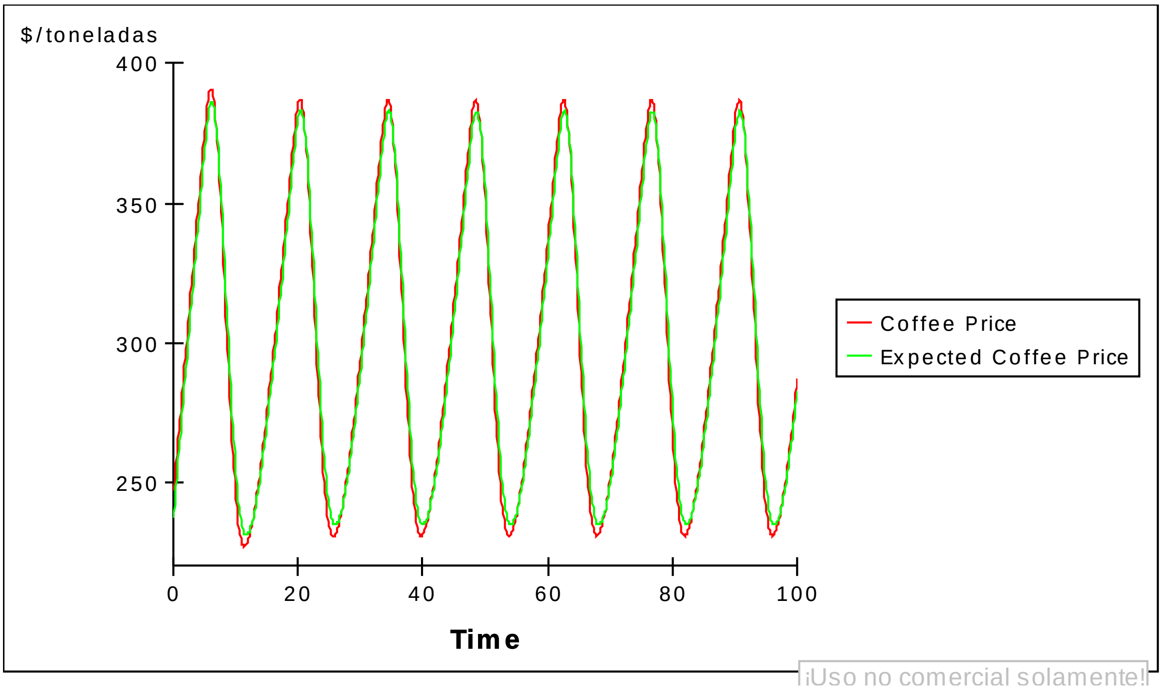


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FIGURE 10. Coffee price and expected price - Coefficient of expectations 0.8

At Figure 10 we can see that changing coefficient of expectation to 0.8 has not effect on coffee price, but the expected coffee price, it behaves almost equal to coffee price sharing oscillations and period.

4.2.2 Parameters in price formulation

In order to make the price function more sensible to the production and amount on hand we increase on 10% the value of the parameters m1 and m2 which means that a bigger amount on hand and/or bigger harvest result on a smaller price.

Figure 11 shows the coffee price oscillations, but the up peaks are 25% smaller than at the base case. With reduction on level of coffee prices we would think that coffee production decrease; the results of Figure 12 show that level of coffee production also decreases around 25%.

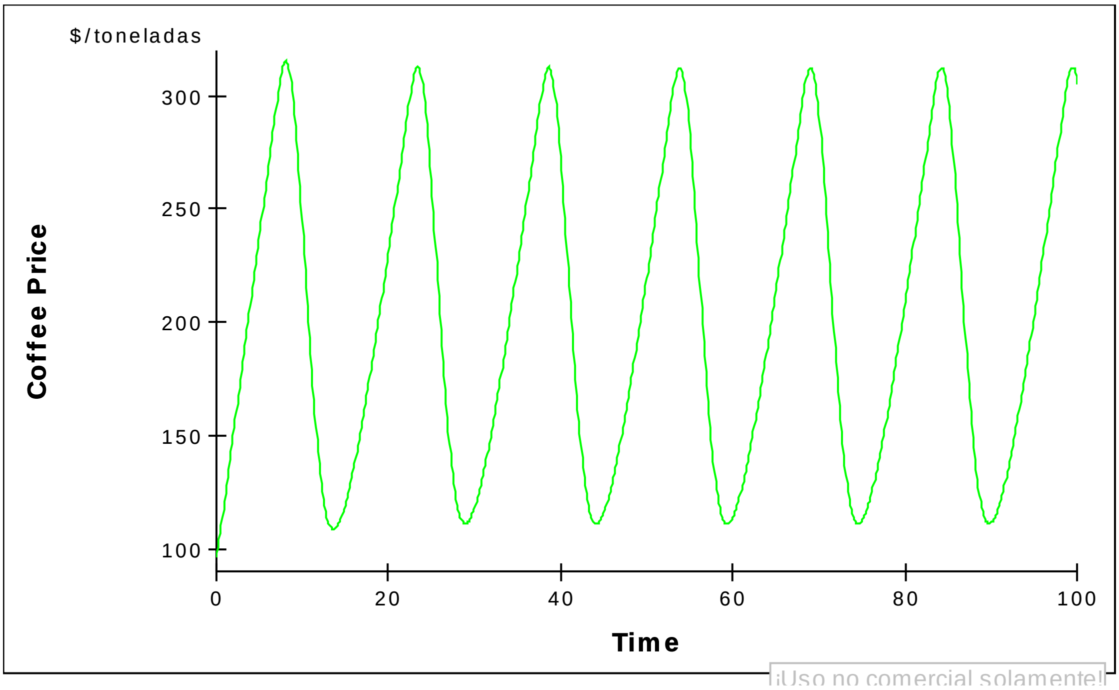

FIGURE 11. Coffee price - Varying parameters in price formulation

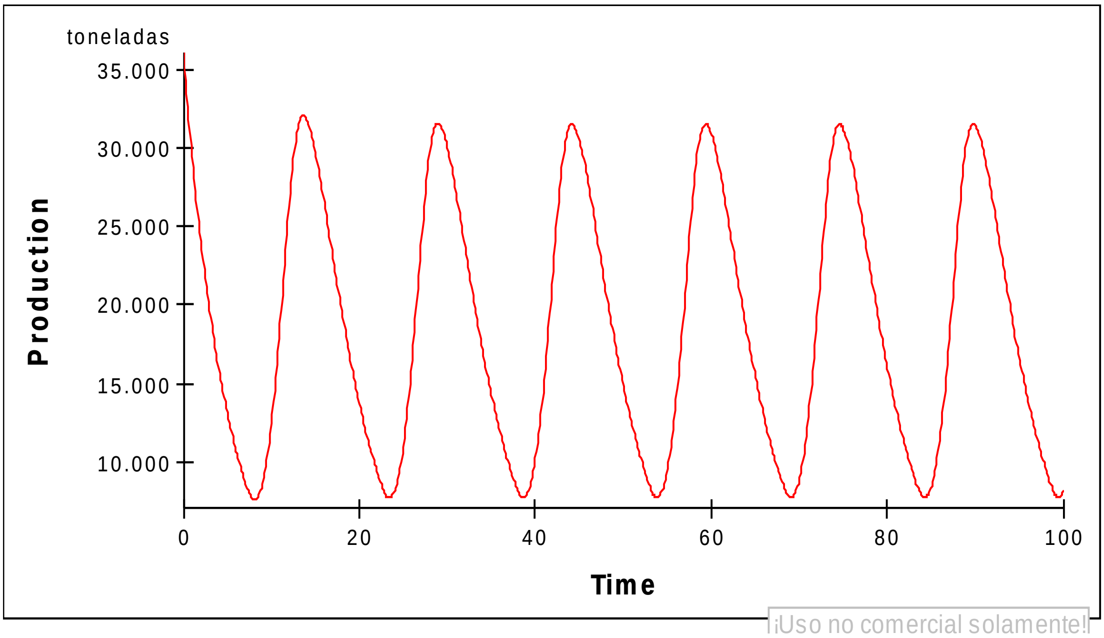

FIGURE 12. Coffee production - Varying parameters in price formulation

4.2.3 Delays

In the model there are two delays, one is the time between a farmer invests on new coffee plantation and the first harvest is available and the other is the time between farmer take investment decision and the moment they invest. This latter delay is equal to 3 years in base case and it will be change.

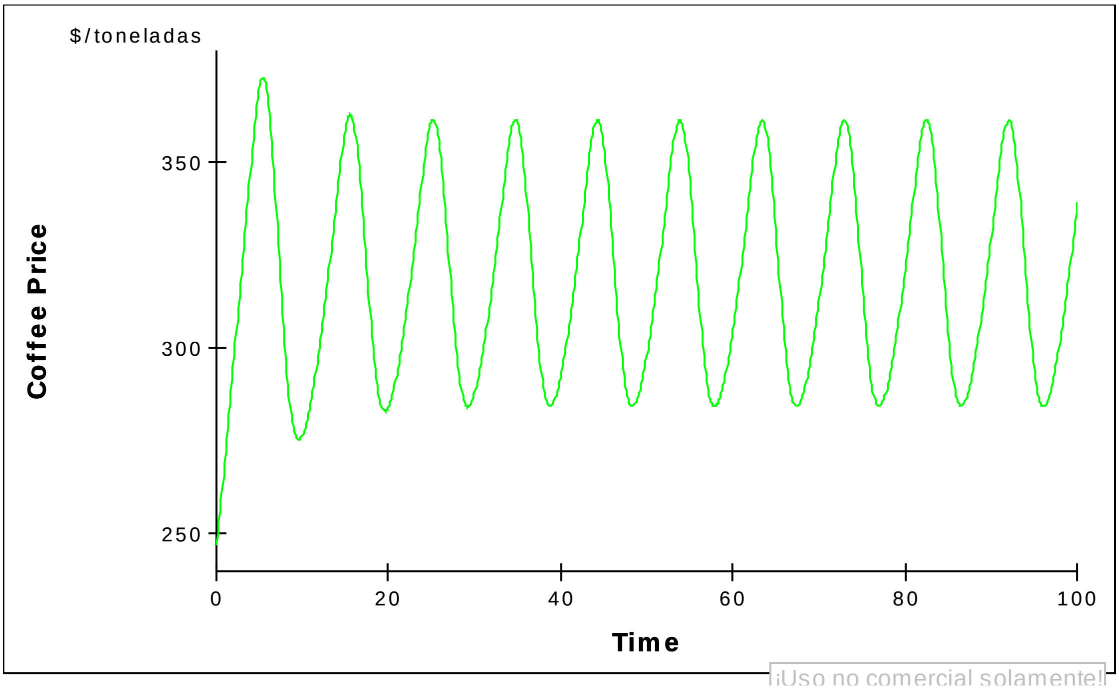

FIGURE 13. Coffee price - Investment delay (2 years)

At Figure 13 we can see that coffee price has smaller oscillations (between $370 and $280 per ton) and its period decrease to 10 years approximated using an investment delay of 2 years.

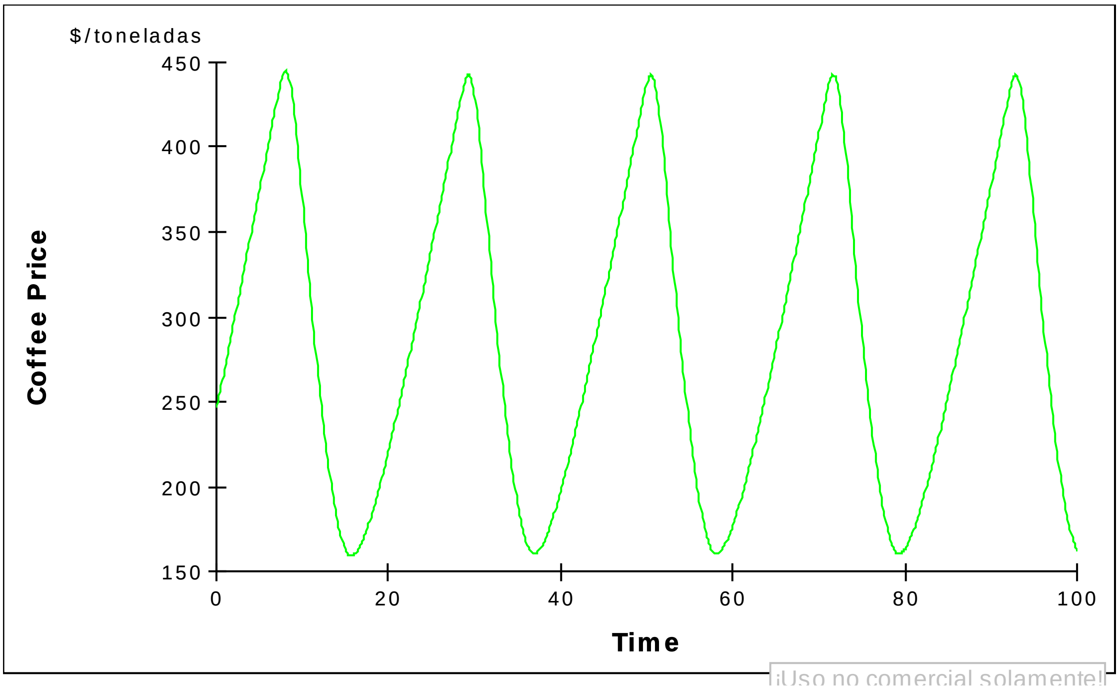

FIGURE 14. Coffee price - Investment delay (5 years)

The cycle originates in discrepancies between supply and demand thus, bigger delays make increase the period of price oscillations as it is shown at Figure 14 (around $150 and $450 per ton) and period increments too (around 20 years).

4.3 Varying investment function: flexible accelerator model

With λ = 2/3, it means that investment is equal to 33% of the desired investment level; at Meadows´ investment function was 100%; both have the same investment delay (3 years).

At Figure 15 we see that coffee price tends to converge in the long-run, but its period is equal during the simulation. It may happen because investment is just a part of desired which production capacity do not exceeds so large the desired production capacity (it means that the level of supply is nearer of its equilibrium point), thus, oscillations converge.

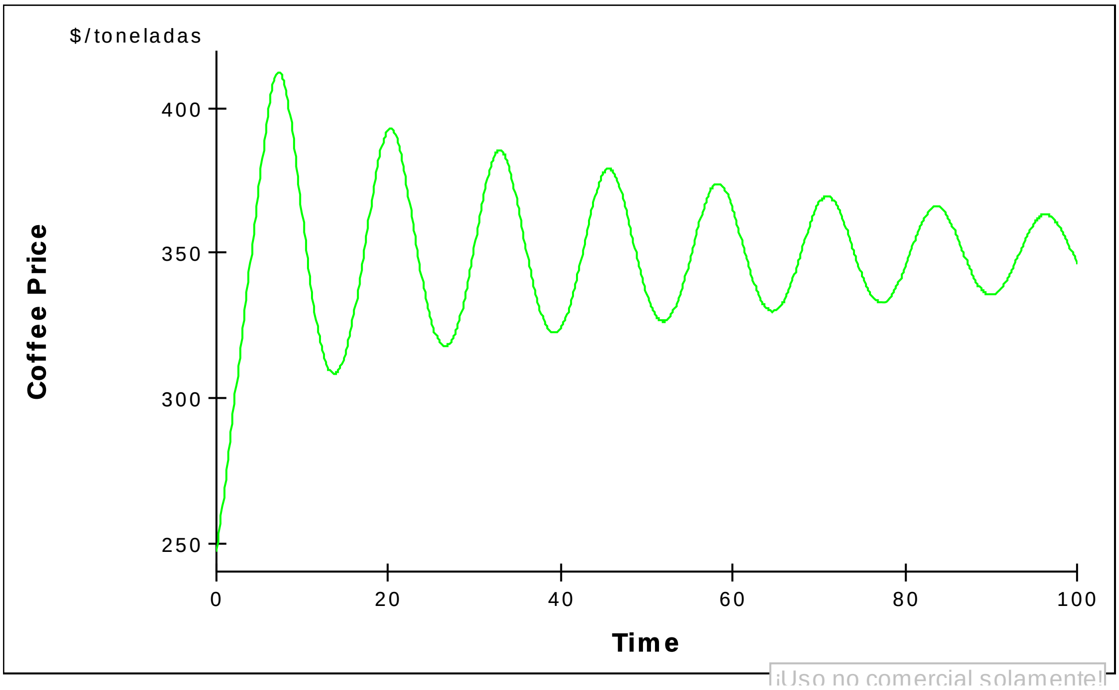

FIGURE 15. Coffee price - Varying investment function

The simulations results have reflected the expected behavior of the system which it is useful to validated the model structure.

5. Discussion

The decision making heuristics and strategies producers use should be modeled including their errors and limitations (Sterman, 1987) in order to be able of reproduce the characteristics of the system. With the available data is too difficult calculate how producers take their investment decision, therefore, Gilbert (2004) suggests that we should get a better understanding of investment decisions in order to be able to reproduce the same characteristics of data.

Laboratory experiments offer a methodological framework to estimate the decision rule in this model, similar to the estimation of the decision rule for capital investment in a simple macroeconomic model (Sterman, 1987) and similar to decision rule for capital investment in a simple electricity market estimated by Arango (2006). Sterman shows that people do not behave optimally despite perfect knowledge of the system structure and perfect information, and even though the environment is highly simplified.

Laboratory experiments could be useful for testing decision rules for subjects in complex feedback dynamics system. In this particular case, we suggest the use of such method to build investment function for the world coffee market. It can be run not only with students, but also with coffee farmers given the accessibility in Colombia. Such experiments could help to get a better understanding of commodity price cycles for coffee.

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