A System Dynamics Study of Instability in the Colombian Coffee Market

by

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Abstract

The coffee market in Colombia is highly unstable, being more unstable in the last 20 years (since the removal of the ICO agreement). During 1980 and 1990 the coffee price was varying around 8% around a mean and over the last 20 years it has been oscillating around 15% to 20% around a mean. The coffee market presents an 8 to 11 years cycle in price and production. Coffee market is well known for its volatility and for the crisis that producers are confronting, i.e., poverty, low prices, etc. The main causes for this crisis are the characteristic behaviors of the coffee market itself, which presents price instability, resource unsustainabillity, and inequity along the commodity chain (specially for coffee growers), the same characteristics of other commodity markets. In this paper we focused on the first of the causes, price instability, and so we created a System Dynamics model of the Colombian coffee sector that captures the structure of that market, the delays and feedbacks present on it. With this research we intended to answer the following questions: Why is the Colombian coffee market so unstable in price and quantity? And what can be done to reduce the instability of that market? The model is an adaptation of the generic structure, created by Meadows 1970 for commodity markets. We demonstrate that cycles in Colombia coffee sector can be endogenously generated and propose some policies that might contribute to dampen those oscillations.

Key Words: Commodity cycles, Colombian Coffee Market, System Dynamics, Price Dynamics, and Coffee Crisis.

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1 Introduction

During the 19th century Colombia experienced rapid economic growth. This faster growing was a consequence of Colombia's economic opening to the world, a process that was led by its coffee sector. Since that time coffee has played an important role in Colombia's economy and it all started because producers decided to sell their coffee abroad. As Montenegro (2007) says "Colombia would not have produced more than one and a half million of coffee bags if the Colombian coffee producers at that time had decided to sell coffee just in the domestic market". After that, coffee became the main source of income for Colombia for more than 50 years. During that period it was the most important good, not only for agriculture sector but for the domestic economy too; it generated capital which helped to develop other industries, increased the country's capacity to import goods and increased Government's income. From that period on the Government endowed with more resources was able to invest in physical and social infrastructure. Although nowadays, Colombia's economy does not depend only on coffee this agriculture commodity still plays a main role in the performance of the country's economy with more than 560 thousands families depending on coffee and being between the three main exported goods of the country, after oil and coal.

We have seen during the past 25 years that the coffee market has gone through different phases but the common denominator in all of them is volatility (Osorio 2005). This becomes clearer by looking at Figure 1.Which shows the International Coffee Organization [ICO] indicated prices for Mild Arabica coffees from 1976 until 2007; the spaces in blank are mainly caused by lack of data for those periods. Figure 1., shows the problem this thesis is addressing graphically. We see in that figure a fluctuating coffee price, presenting cycles of 8 to 11 years of duration. One can see two complete cycles in that graph. The first cycle starting in month 15 (1977) when coffee prices were at above 300 U.S. cents per pound and ends around month 127 (1987) when coffee prices were at around 260 U.S. cents per pound. Next cycle ends around month 257 (1997) and one can observe that around month 324 (2003) prices are rising again and it continues rising until the end of the graph (2007), probably in one or two years (2009 or 2010) we might be seeing another decrease in prices, if the cycle continues.

If one considers that commodities, for some developing countries, are the main source of export earnings and are a big source of employment, then one can realize why those cycles or fluctuations have a negative impact on producers, consumers and some countries. In fact, ca. 17 to 20 million families (worldwide) are affected by these fluctuations. According to Lewin, B., Giovannucci, D.,Varangis, P. (2004): "*In several coffee-producing countries, coffee accounts for at least 20 percent of the total export earnings. By some estimates, approximately 100 million people are directly affected economically by the coffee trade. It goes without saying that with a crop of such significance for some countries, the destabilizing effect of the price crisis sparks concern precipitating bank failures, public protests, and dramatic falls in export revenues*"(p11). This situation is also affecting Colombia, where coffee plays an important role, not only economically but also social and culturally. Although many authors claim that due to the labor of the Colombian Coffee Growers Federation (FNC for its name in Spanish) the situation in Colombia seems to be less dramatic than in other producer countries, we will discuss this hypothesis further in the following sections, more specifically on section 6 of this thesis.

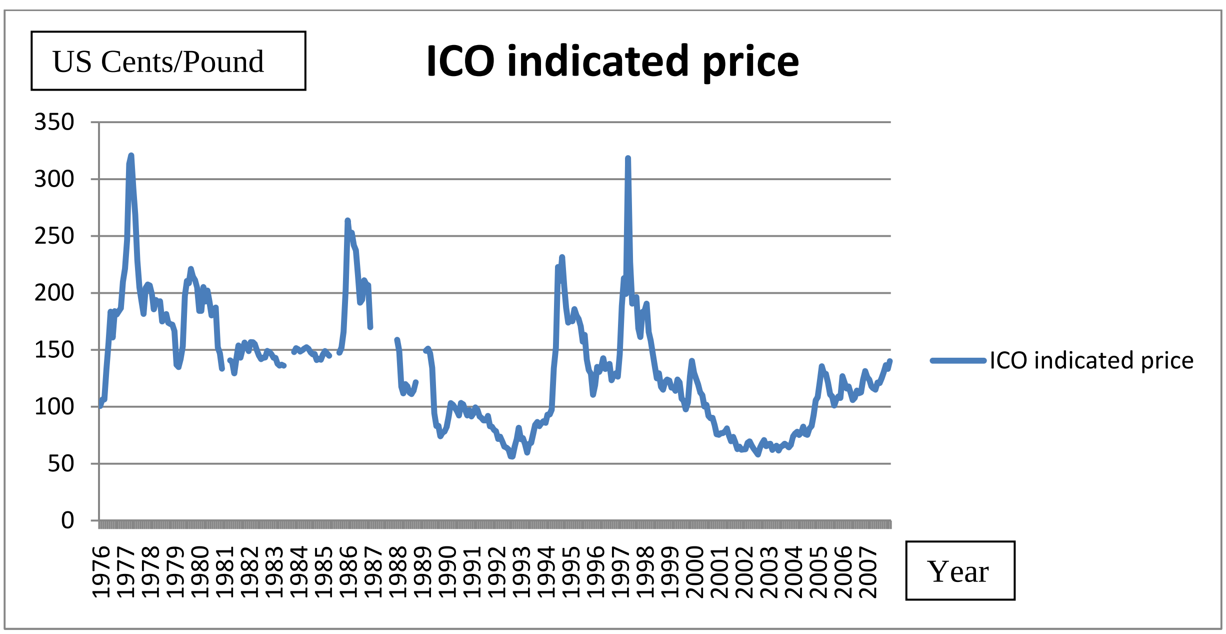

Figure 1. Monthly ICO indicated prices 1976-2007

Source: www.ico.org

The fluctuations combined with the fact that coffee prices have been at very low levels over the last years has caused governments, institutions and coffee growers to create policies in order to stabilize the world coffee price. There have been several attempts to increase and control the world coffee prices but those attempts either failed or are discontinued (like the ICA[1]), so the problem of both, a decreasing price and instability remain, and given the importance of such commodity for Colombia and other countries it is very important to try to find a solution to those problems. This thesis will focus on the problem of fluctuations and instability and so, we formulated the following research questions that we intended to answer in this paper:

- Why is the Colombian coffee market so unstable in price and quantity?
- What can be done to reduce the instability of that market?

By answering the previous questions, this thesis tries to understand the characteristics of the coffee price by understanding the dynamics present in the coffee sector, for that reason the purpose of this thesis is to provide a System Dynamics model of the Colombian coffee market and to test some policies to stabilize it, this paper does not intend to predict the future of the coffee market but it tries to study some possible scenarios and/or the consequences of implementing some stabilization policies. We will try to reach this goal by studying the long term dynamics involved in such market.

The reason for this study is the importance that coffee has for Colombia's economy and its development and the role Colombia plays in the international coffee market and the influence it has on this specific market. Although lately, Colombian's coffee share in the world market has reduced. Colombia passed from being the second largest producer and seller of Arabica coffee worldwide to be the third one overtaken, by Vietnam who in the last years has been increasing its coffee production. It is also worthy to notice that the significance of coffee in both Colombia's GDP and Exports has decreased. However, not only Colombia is being affected by this trend in coffee prices: other coffee producer countries are having similar problems. In general, we can say that commodity producers' countries (especially those who depend on those commodities) present this type of problems.

[1] ICA: International Coffee Agreement

Here we can say that coffee is not the only commodity presenting this type of undesirable behaviors. Several other commodities present all types of fluctuations in: inventories, production activities, earnings, capacity, etc. and these irregular patterns have – as in the coffee case - persisted over years. This is important to know because it means we can also learn from the experience in other markets where System Dynamics has been used trying to give solution to the same type of problems. Those studies gave us hints for our modeling process.

We used as point of departure for our research the work by Meadows (1970). He developed a general structure for commodity markets. So we started from this general structure and adapted it for the specific case of the Colombian coffee. We can divide our model into two sectors; Supply and Demand side. We developed a very basic structure able to replicate the cycles we see in the coffee sector and one of the first steps we took in building the model was to review the existing literature about modeling coffee markets.

Commodities in general have been case of study in many different areas. Coffee, considered one of the world's most important commodity markets, has been studied by several authors and in most cases the author used econometric models (when the focus of the study is similar to ours). Here we tried to learn more about this complex system using the System Dynamics methodology.

> Sterman (2000) defines system dynamics as:
>
> A method to enhance learning in complex systems… it helps us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies... It is fundamentally interdisciplinary. Because we are concerned with the behavior of complex systems, system dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. (p.4)[2]

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[2] Sterman (2000). For a larger explanation of System Dynamics see appendix A

System Dynamics has been used to analyze more deeply other commodity markets (Sawmill Industry, Jones, A.; Seville, D.; & Meadows, DH, 2002, United States Hog market, Landel, 1971, shrimp market, Johnston, D., Soderquist, C., Meadows. DH., 2000), some of the studies are related with general structures for commodity markets and some other are focused on specific commodities, but there is no evidence of studies of this type for coffee. In the following chapter we will review the existing literature about coffee markets or commodity markets in general, both with and without System Dynamics.

This thesis intends to answer the previous mentioned research questions and to give a look to the actual situation of the Colombian coffee sector from a system dynamics perspective. It is organized in 8 chapters including this introduction. Chapter 2 summarizes part of the existing literature and previous works for the problem treated here. Chapter 3 states the problem more detailed and explains the systematic behavior we considered to be problematic. Chapter 4 goes through the explanation of the dynamic hypothesis using CLD (Causal Loop Diagrams). Chapter 5 is a description of the model, including the model’s boundaries, assumptions and structure. Chapter 6 consists of a group of tests for the validation of the model (Boundary test, dimensional consistency, extreme condition test, among others). It also focuses on the behavior, trying to understand the dynamics behind the cycles in the Colombian coffee sector. Chapter 7 focuses on the policy design which we will use to try to change the behavior by changing the structure. The last chapter summarizes the conclusions found during the current study and also gives the possibilities of future work.

2 Literature Review

2.1 Non System Dynamics modeling about the coffee sector

The world coffee market has been modeled several times but despite of the number of existing models, the long term dynamics involved have not been deeply analyzed (Akiyama & Varangis, 1990) and this is due mostly to two factors: the time required to capture the long term dynamics of supply, and the lack of good historical data on coffee tree stocks (Metha & Chavas, 2008) Commodities, in general, have the same problem and their dynamics remain poorly understood. Arango (2006), mentions that most of the authors in economics simply ignore the problems in commodities process or according to some authors deal with them with the highly simplified cobweb model. Given the importance of such commodity for some of the producing and exporting countries, several attempts to control the coffee price have been made, but still this continues fluctuating in a decreasing trend (Oxam, 2002, Espinal, C. F.; Martinez, H. J.; Acevedo, X. (2006); Cashin & McDermott, (2002))

As Lewin et al, (2004) described: "*coffee prices since 1970 have averaged a 3 percent decline per year for Arabica coffees and a 5 percentage decline for Robusta…we characterize the price decline as series of cycles of about 7 years duration within the falling trend*" (p.19) They give a combination of possible causes for this problem (rising producer share of export prices, increasing in productivity and others) but yet there is a lack of understanding on how to stabilize coffee prices. It may be this lack of understanding, one of the reasons why during the last few years, most of the models and studies of the world coffee market are focused on the effects of International Coffee Agreements on the world coffee prices (although that is not the focus of our research)

Mehta and Chavas (2008) make an interesting classification of some of the existing works about the world coffee market and the impact of ICA. They referred in their article to four groups of studies classified as follows: "Structural studies", "estimated reduced-form time series specifications of price dynamics", "studies of market power at the retail and roasting level having a either structural or descriptive approach" and the last group concerned about "policy instruments utilized by producing countries".

Here we will use the same classification to describe some of the existing models of the world coffee market but using only three of the groups, since for the sake of this research the second and third group can be merged into one single group. We will also try to expand the list of models the authors have on each group.

Structural studies of the world coffee market as Mehta & Chavas (2004) "*utilize annual or quarterly data to estimate equations governing some combination of planting, output, export supply, demand, inventory accumulation and risk preference equations (governing the clearance of futures markets) for a representative number of producing and consuming nations*" (p. 286)

- Ford (1978) created a model for the world coffee market to test the effects of stabilization policies on that specific market. Some of the policies he evaluated on his work included coffee tax variations, changes in Brazilian diversification program, and buffer stock schemes. His analysis was focused mainly on the size, cost and effects of the last type of policies (Akiyama and Varangis, 1990)
- Hamman F (1996) investigated the existence of nonlinearities in the world coffee price time series and then he specified, estimated and verified an autoregressive model which tried to include a specific kind of nonlinearity. The model let the author test whether price dynamics are different when prices are going up or down. He concluded that world coffee prices can be properly described with a linear model allowing intervention, but he also says that a non linear model could be more interesting in order to analyze some aspects of the world coffee market, such as, the dynamics of the world coffee price that seems to behave different when prices are at high levels than low levels.
- Akiyama and Varangis (1990) analyzed the impact of the international coffee agreement on the world coffee market, to do so they ran some simulations of a global coffee model. They found that during the last years of operation of the International Coffee Agreement, it served its purposes, e.g., it did have a stabilizing effect on the world coffee price. They

also analyzed the effect of the quota agreement for both small and big producer countries; but not in the same way big producers were benefited by the agreement per se but small producers were only benefited in risk terms since their real export revenues decreased when the agreement was in use.

- Deaton & Laroque (2003) developed a model based on Sir Arthur Lewis' paper[3]. They elaborated a series of models (statistical models to be more precisely) of commodity prices for wide variation of tropical commodities, coffee was including among them. In their models "the prices are stationary around a long-run trend, production is co-integrated with world income, and supply responded to deviations of price from its long-run equilibrium". They managed to fit their model to five more commodities besides coffee. Although they were not mainly focused on the world coffee sector, they managed to build a general commodity model able to replicate some of the characteristics of the mentioned commodity, yet they were not focused on stabilize those markets.
- Palm & Volgelvang (1986) built an econometric model for the world coffee market for the major importer and exporter countries. They wanted to model the price formation on spot and futures markets, coffee consumption (for the most important importing countries), inventories (both supply and demand sides) and the trade flows involved on this market. They derived the behavioral relationships for producers, inventory holders, speculators and consumers from optimizing considerations in an uncertain environment. They assumed in their model that the actors in the market (e.g. producers, dealers, speculators) have access to the spot and future markets and given a time horizon of two periods they maximize the expected value of the utility of profit. They had a predetermined production on their model, they treated coffee as one homogeneous product (i.e., they didn't distinguish among the different types of coffees)

The main weakness of this set of studies is that the authors made some very restraining assumptions, some of these assumptions include constant demand, constant or exogenous production, by making this type of assumptions they might have restricted some important dynamics effects.

[3] Lewis, A., (1954). Economic development with unlimited supplies of labor. Manchester School 22, 139– 191

Estimated reduced-form time series specifications of price dynamics "*These studies are concerned with short term price transmission issues and seek evidence regarding the allegations of growing market power in the coffee roasting and retailing sector through the 1990s*" (Mehta & Chavas, 2008, p. 287)

- Metha and Chavas (2008) built an econometric model of price dynamics and include farm, wholesale and retail coffee prices, they investigated the economics and dynamics of the impact of price interventions (such as ICA) in coffee markets. They were focused on farm prices in Brazil and decided to focus on the prices of commodity coffee because that is the greater part of the coffee that is produced worldwide and as they discussed that had a cost because nowadays, because the niche markets are gaining importance.[4]
- Sheperd (2004) in this analysis Sheperd creates a model of price transmission from producers to the world market and from world market to the consumers. He made a comparison before 1989 and post 1989[5]. He wanted to answer whether there is something special about the structure of the coffee processing chain that could contribute to cause the impoverishment of ordinary coffee farmers. More specifically whether the roaster agents are able or not to slow down or hamper the "expected benefits of liberalization?" he called it "profiteering roasters hypothesis" so what he argues is that the roasters are large enough to influence market outcomes. Some of his conclusions are: "Market liberalization has not helped as it was expected the results of the liberalization in some cases seems to be worse than before" (like, Asymmetric price transmission, margins increase on the consumer side, etc.) Regarding his hypothesis, he considered there is more work that needs to be done in order to give a concrete answer to it.

Studies concerned about policy instruments utilized by producing countries:

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[4] See Lewin, B., Giovannucci, D., Varangis, P., 2004. Coffee Markets: New Paradigms in Global Supply and Demand. Agriculture and Rural Development Discussion Paper, vol. 3. World Bank, Washington D.C.

[5] Previous the rupture of the ICO and after it.

- Patron, H (1995) created a model using game theory to study whether the retention agreement was the best situation compared with the one were no pacts among producer or importing countries were on. The retention agreement was signed after 1993; by this agreement the countries who formed part of it, agreed to retain a certain amount of coffee depending on the prices for coffee[6]. The limitations of this model are mainly: the assumption of equality among international and domestic prices, homogeneity of coffee and a stable supply as well as excluding the demand (or treat it as an exogenous input to his model)
- Cardenas, J.H (1994) made a study with the same characteristics than the previous described, the main difference between these two works is the conclusion about "self-enforceability" of the agreement. While Patron, H concluded that the agreement is "self-enforceable" for the "big countries" Cardenas did not; possible causes for this discrepancy are: the static characteristic of Cardenas' model or the different between the cost structures for inventories of both models.
- Bohman, M., Jarvis, L., Barichello, R (1996) examined the effects of quotas in the context of international commodity agreements. They did not focus on terms of trade and export revenue instability but in welfare effects of commodity agreements within exporting coffee countries (focused mainly on Indonesia's case) They said "…quota rents create an incentive for rent seeking resulting in a previously unidentified welfare cost of ICA quotas" and "that rent-seeking losses can potentially outweigh any gains from higher prices caused by the ICA" (Bohman, M., Jarvis, L., Barichello, R ,1996, p399)

The present research could be placed in both the first and the last group of studies.

As mentioned before, the most significant weaknesses of these set of models are the assumptions the authors made to build their models, assumptions such as constant demand or constant production which, from our point of view, are very restrictive. In our model we try to make those variables endogenous since we consider those as an essential part of the structure that originates the cycles in this market. We take some common structures and relationships between variables

[6] For more information on retention agreement see www.presidencia.gov.co/prensa_new/decretoslinea/1993/septiembre/22/dec1900221993.doc

from these set of studies and translated them into System Dynamics structures. The second set of studies are not directly related with our research since they only focus on the effects of agreements on coffee prices, and the role of some actors (like roasters) on determining the price received by the farmer, yet we found those articles relevant to present in this paper because from there we were able to identify the functioning of some structures (specifically capacity, e.g. productivity of coffee trees) present in the coffee sector.

2.2 System dynamics modeling about commodity markets

System Dynamics (SD) was developed based on the work of Jay W. Forrester and his book Industrial Dynamics back in 1961. SD is a methodology to understand the behavior of complex system (systems with feedback structures and delays) over time. It uses the concepts of feedback and stock and flows to represent the structures underlying a specific system. We will explain more deeply some of the concepts of SD in one of the appendixes; in this section we will focus our attention on the existing literature on commodity markets where the SD methodology has been used.

In the case of SD there is no evidence of studies about the Colombian coffee market. On the other hand there are some models for commodities in general (DL, Meadows, 1970, Sterman, 2000) and some other models for specific commodities (Landon, 1970, Johnston, Soderquist & DH Meadows, 2000, among others) that could contribute to this research, in the sense of giving insight about modeling commodity markets using SD.

Meadows DL (1970) addressed the following questions on his book "Dynamics of Commodity Production Cycles": *"Why do prices and production of commodities fluctuate? Is the cyclical behavior unique to each commodity or is it due to a common structure underlying all commodities?"* In his book he developed a general theory for commodity systems and the cause of their instability, and so he developed an Industrial Dynamics model of a generic commodity market using DYNAMO (system simulation software developed by Phyllis Fox and Alexander Pugh[7]). He also tested this theory by adapting his generic structure to two specific commodity systems; the U.S. hog market and Chicken commodity system, in both cases obtained the same conclusion; the generic structure is well suited when some specific changes (biological characteristics of the good in question) are made.

Landon (1970) created a model able to reproduce the characteristic behavior of the United States hog market using the SD methodology to explain how the long-term pork cycle depends on:

[7] http://www.systemdynamics.org/DL-IntroSysDyn/origin.htm

organizational structures, operational policies and information flows within the pork system, leaving any possible external explanation out of possibilities. He wanted to identify the controlling feedback structures that determine the cyclic behavior of the pork system. He also wanted to demonstrate that all the characteristics of the observable market variables arise from the feedback structure. He concluded that it is the own pork system who gives rise to the unstable behavior, specially the activities made by producers and meat packers. On his study he was able to demonstrate that most of the exogenous variables have little or no influence on the system's behavior.

Based on the work done by Meadows DL (1970), Sterman on his book "Business Dynamics: Systems Thinking and Modeling for a complex world" build a generic model for commodity markets and report about a model built for the paper industry. This work together with the one from Meadows DL do not talk about the coffee commodity system itself but both of them gave greats insights about commodities in general and both also give very useful formulations that could be used in many other commodity models. Sterman tried to explain the source of the fluctuations present in many commodity systems arguing that the source was, in most cases, the structure of the commodity market itself, e.g., it was possible to find and explanation for the oscillations endogenously.

Johnston, Soderquist and DH Meadows, (2000) worked with three types of commodities (shrimp, corn and forest) at the Sustainability Institute in order to find ways to make these types of systems more stable, sustainable and more financially secure. They modeled the shrimp commodity system. They found that the shrimp system itself operates in a very inefficient way, and the reason being the long term delays existing in the system (specifically the delays in the response of price to production and vice versa, which could be a good thing to test also in the coffee commodity system)

As part of their research on commodity systems Jones et al., (2002) also studied resource un-sustainability in the forest products economy. In this case, and differing with other research, they did not focus on instability or on inequity (some other undesirable behavior in commodity systems) but they focused on commodity extraction and processing as the major sources of unsustainability. They show that this specific commodity has the structural potential to overshoot[8] the long term supply of the forest resource. They also point how many of the policies commonly promoted are unlikely to solve the problem. Although the last two types of research have a different scope (e.g. they are not mainly focused on instability) they give us an insight of commodity system modeling using System Dynamics.

Abaunza, F., and Arango, S. (2009) built a SD model for the world coffee market also based on Meadows model. Their intention is to estimate investment functions through laboratory experiments.

So far, a SD model for Colombia's coffee market has not been built. Since with SD methodology we could capture the long term dynamics (such as the effect of price interventions, long term investment delays, etc.) existing in this system, it is appropriate to develop a study to test some of the available options (Coffee Growers Federation, Price limiters, quotas schemes, among others) to bring balance to this particular commodity system because it is well know that coffee and other kind of commodities are often characterized to be unstable in both price and quantity.

[8] See Sterman, (2000) for a description of this and other types of behavior. Pp 107-134

3 Problem Statement

In this section we describe the problematic behavior in detail; we also construct our reference mode based on historical data of the Colombian coffee sector. Finally we state why we consider this problem to be important and show the limits of our project; ending with some questions that we intended to answer with this research.

Through years coffee prices have been subject to volatility. The several attempts to reduce such volatility and make the market more stable have not succeeded though, i.e. the problem of instability persists. As mentioned before this thesis is focused mainly on formulating policies to reduce the fluctuations on the Colombia coffee market. To understand more the problem let us have a look to some graphs that will show us its evolution over time. Figure 2. shows yearly average prices for Colombian mild Arabica coffee, the time series starts at 1976 and ends at 2007. During these 31 years one can see two complete cycles on the coffee price index for Colombian mild Arabica, one starting around 1977 and ending around 1986; and the second one ending around year 1977, this will become clearer when we have a look to Figure 4. There are two aspects to highlight from Figure 2.: first, the types of dynamics behavior we can observe there, and second, the way how fluctuations (our problematic behavior) have evolved over that period of time.

Usually the definition of a dynamic problem is based on historical data but that data alone is not the problem, because normally the historical data contains noise, external events, and other things that perhaps the modeler is not interested in, and does not want to explain with the model. The first step in defining the problem is deriving the reference mode from the historical data. And here we are going to follow the guides given in Saeed (1998) on his paper “Defining a problem or creating a reference mode”. We will specially focus in the section where he talks about “complex time histories”: “Since models cannot be made overly complex if they are to remain understandable, complex problems must be sliced into smaller parts so that the parts meet the requirements of the intended policy design” (Saeed, 1998,p. 22) . In other words, decompose the historical data into multiple modes (characteristic behaviors) so that the model remains easy to understand and serves the purposes of policy design. Keeping this in mind lets go back to the description of the problem this thesis addresses.

Figure 2. and Figure 5. represent what Saeed calls "historical evidence", and they show the behavior of Colombian coffee prices and Colombian coffee production from 1976 to 2007 respectively.

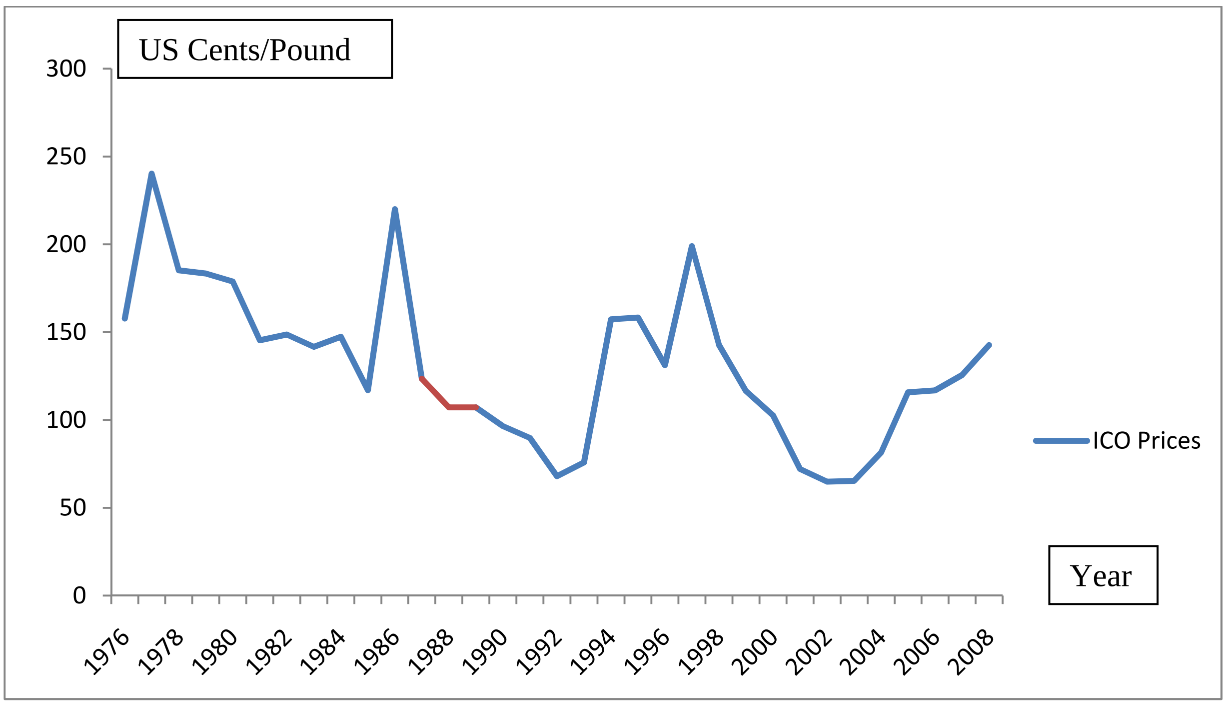

Figure 2.ICO indicated prices Colombian mild Arabica group yearly average (US cent per lb)

Source: www. ico.org

So to continue with Saeed's recommendations we should then slice these data series to show only the part we are interested in. So let us start by depicting the types of behavior that composes the first of the time series[9], e.g., the different patterns we can observe in Figure 2. There are mainly two different behavioral tendencies in that figure; first, a downward trend (Figure 3.) and second,

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[9] We followed the same method to de-trend the data of the two time series. In order to measure the downward trend of each of the data series we used a linear regression with Excel For the oscillatory patterns, the period was estimated by counting the years between peaks and then calculating an average of those times. The amplitude of the cycles was estimated calculating the difference between the high and low points of each of the 3 cycles in the data series and also averaging those. We then built a sine wave with this information (Amplitude and period) to use as a reference mode

oscillations (Figure 4.). We are interested in the second type of behavior; mainly because in terms of policy relevance the downward trend is smaller compared with the variability of prices[10]; according to Cashin and McDermott, (2002):

> *…in contrast, rapid, unexpected, and often large movements in commodity prices are an important feature of their behavior. Such movements can have serious consequences for the terms of trade, real incomes, and fiscal positions of commodity-dependent countries, and have profound implications for the achievement of macroeconomic stabilization. (*p.196*)*

The second reason to focus on the oscillations is because we think that once the problem of oscillations is solved it will be easier to approach the problem of the decreasing prices. We tried to decompose the ICO prices data series into two graphs so that it will be clearer to show each of the tendencies we mention here.

To split the graphs we inspected the data instead of doing a formal statistical decomposition. The purpose is to depict general trends, and we just took into consideration other authors´ analyses or their/ours estimations. Figure 3., for example, shows the falling trend in price, which according to Lewis (2004) Mild Arabicas' coffee price falls around 3% every year for the Arabicas group (p. 19).

[10] We are not saying the downward trend in price is not important; but for the sake of this research we will be focus only on the oscillations.

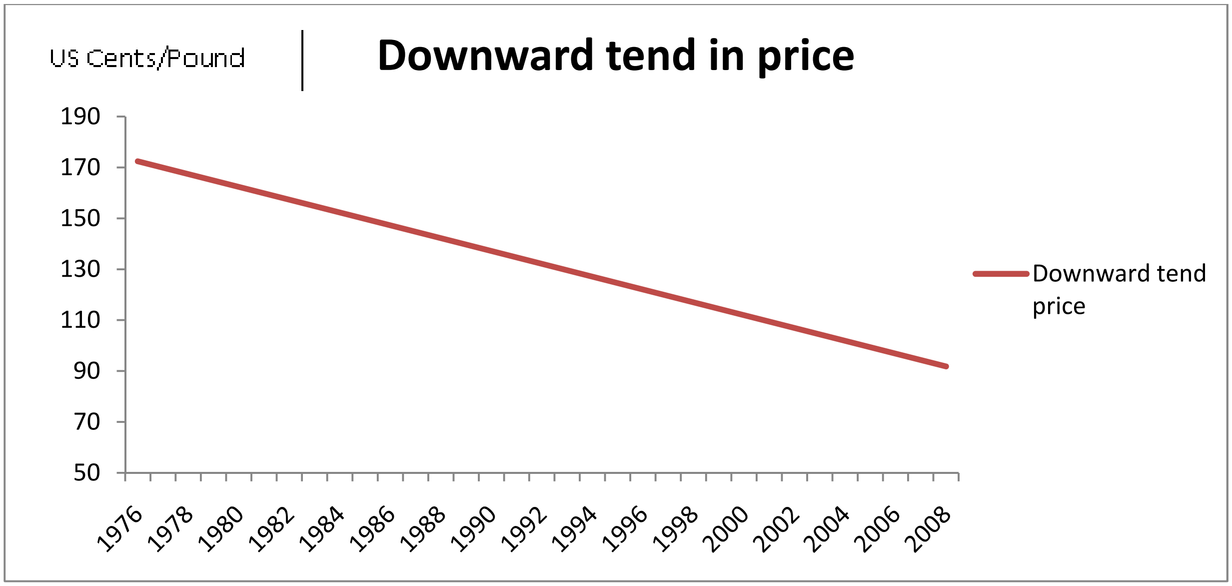

Figure 3. ICO Downward tendency

Source: Estimated trend line from Original data series for Colombian Mild Arabicas Price

On the other hand we have Figure 4. that shows the second behavior that composes Figure 2. Figure 4. shows the characteristic behavior we are expecting to reproduce with our model in order to test our hypothesis of whether part of those fluctuations are caused by the structure of Colombia's coffee sector. Figure 4. shows cycles with an amplitude of 53 (us cent/lb) and period of approximately 8 to 11 years; as we mentioned previously one can observe two complete cycles[11] one starting around 1977 and ending around 1987 and the second one from 1987 and ending around 1997; we also expect cycles in production but with opposite movements, e.g., when prices are at a maximum, production is on a minimum, we can confirm this by looking at Figure 6. -that shows Colombia's coffee production from 1977 to 2006- and compare it with either Figure 2. or Figure 4. One can see how around 1987 prices were at a maximum level while during the same period production was at minimum. Likewise, during 1991 Colombia coffee production seemed to be at a maximum while prices during that period where at a minimum.

[11] We consider a complete cycle when price reaches its previous peak.

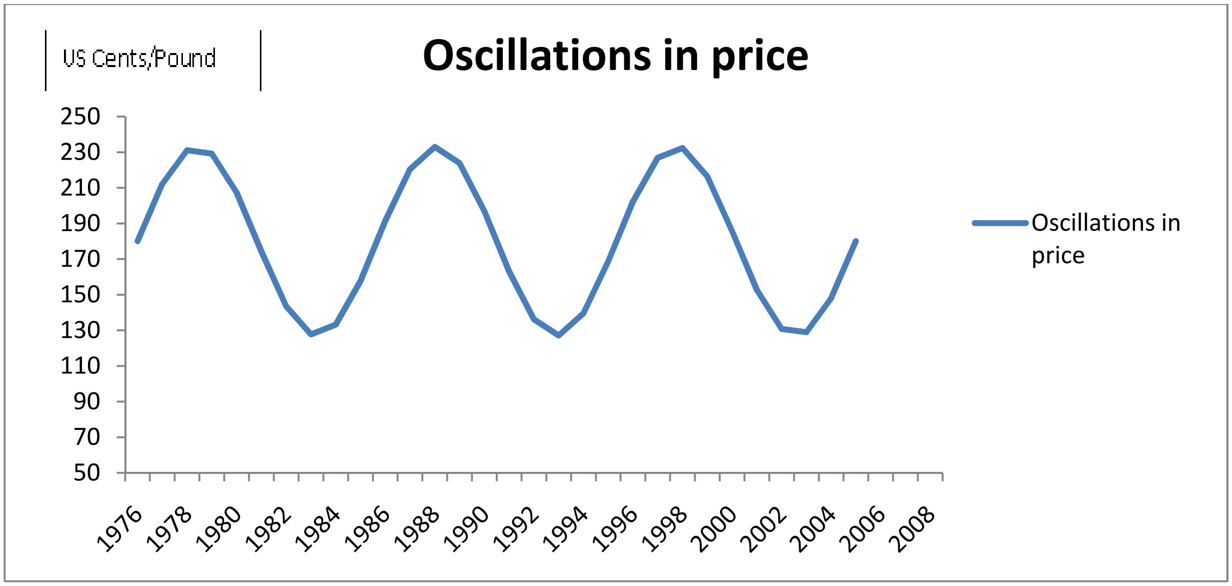

Figure 4.Oscillations in price. Reference Mode

Source: Estimated tendency from original data series.

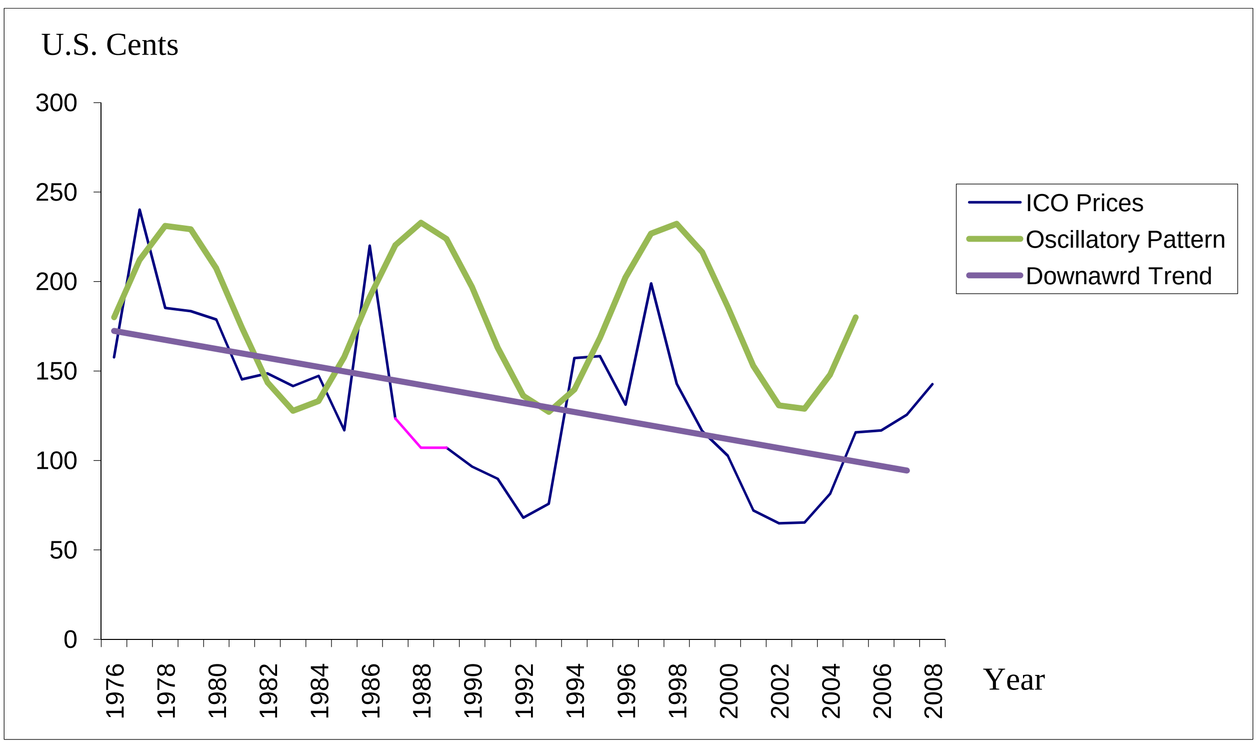

Figure 5. Comparison of estimated trends with the original data.

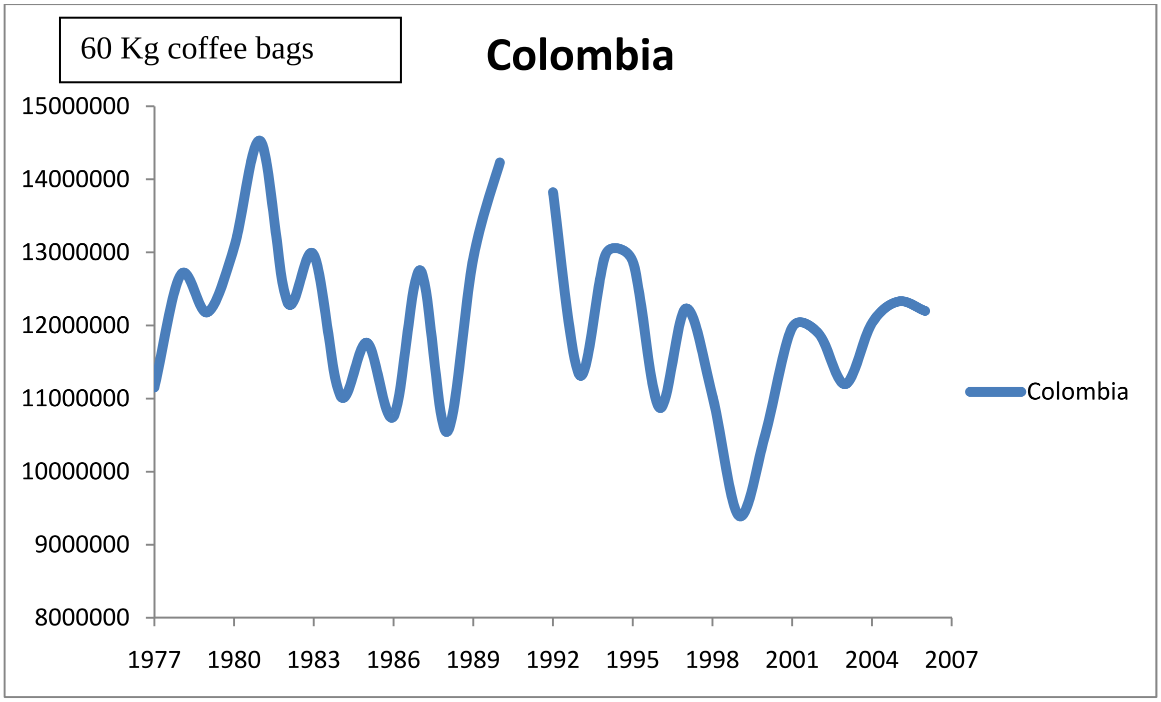

Figure 6.Colombia's coffee production

Source: www.ico.org

Let us decompose Figure 6. into two graphs, as we did with the coffee prices. Likewise, we found the same two types of behaviors downward trend (Figure 7., although is not as steep as in the price time series) and oscillatory behavior (Figure 8.)

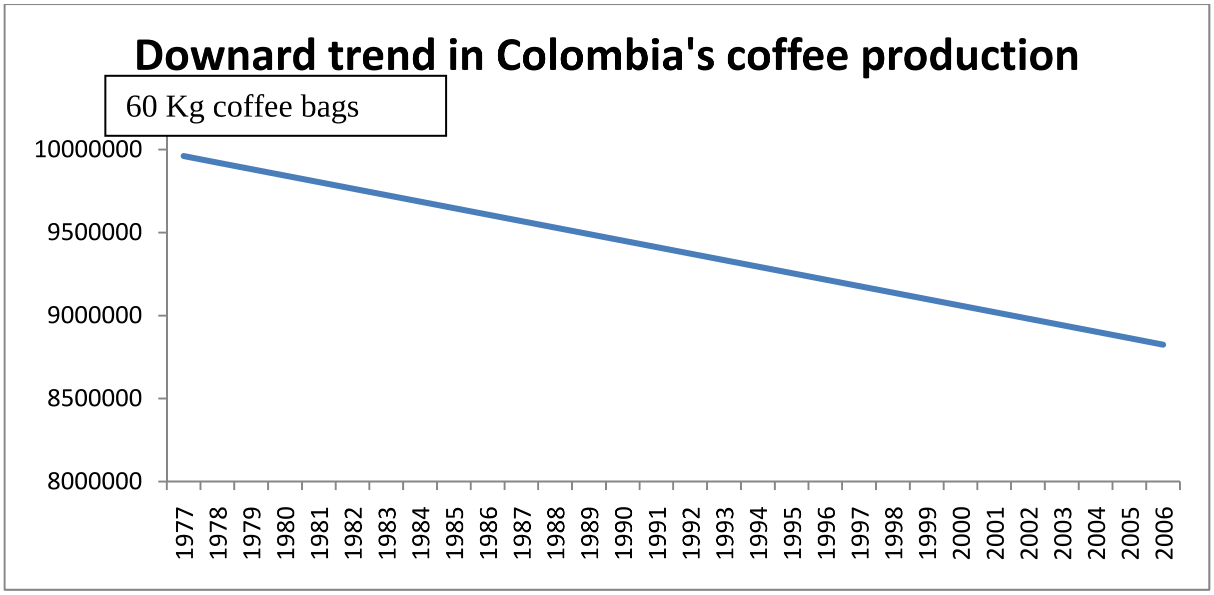

Figure 7. Downward tendency of Colombia's coffee production

Source: Estimated trend line from Original data series for Colombian Mild Arabicas Price

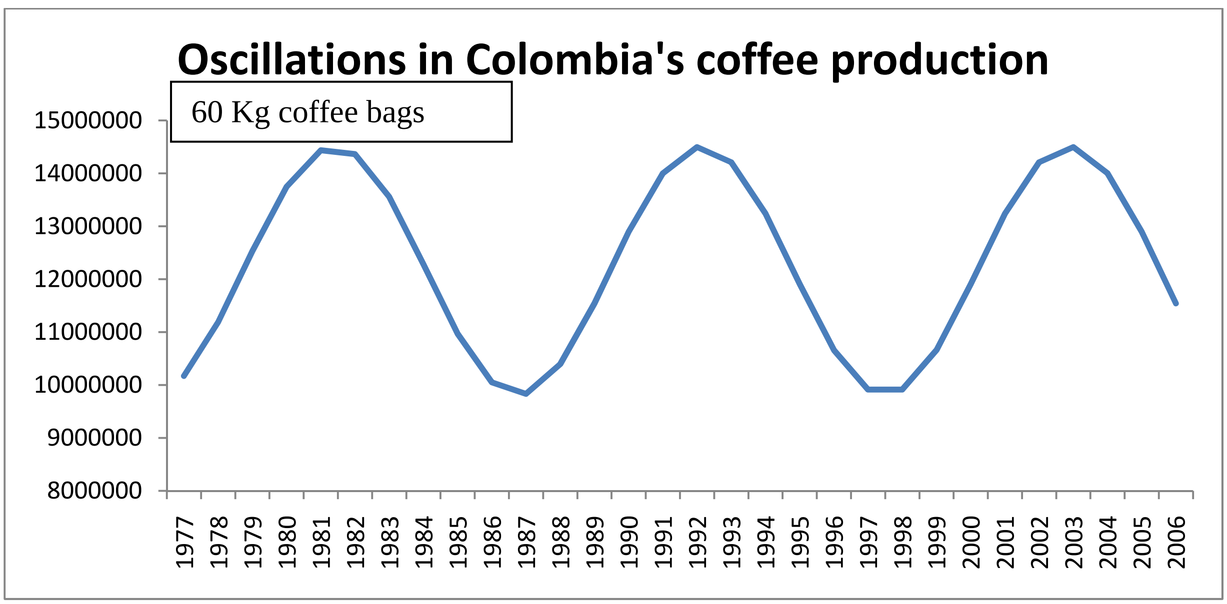

Figure 8.Oscillations in Production.

Source: Estimated tendency from original data series.

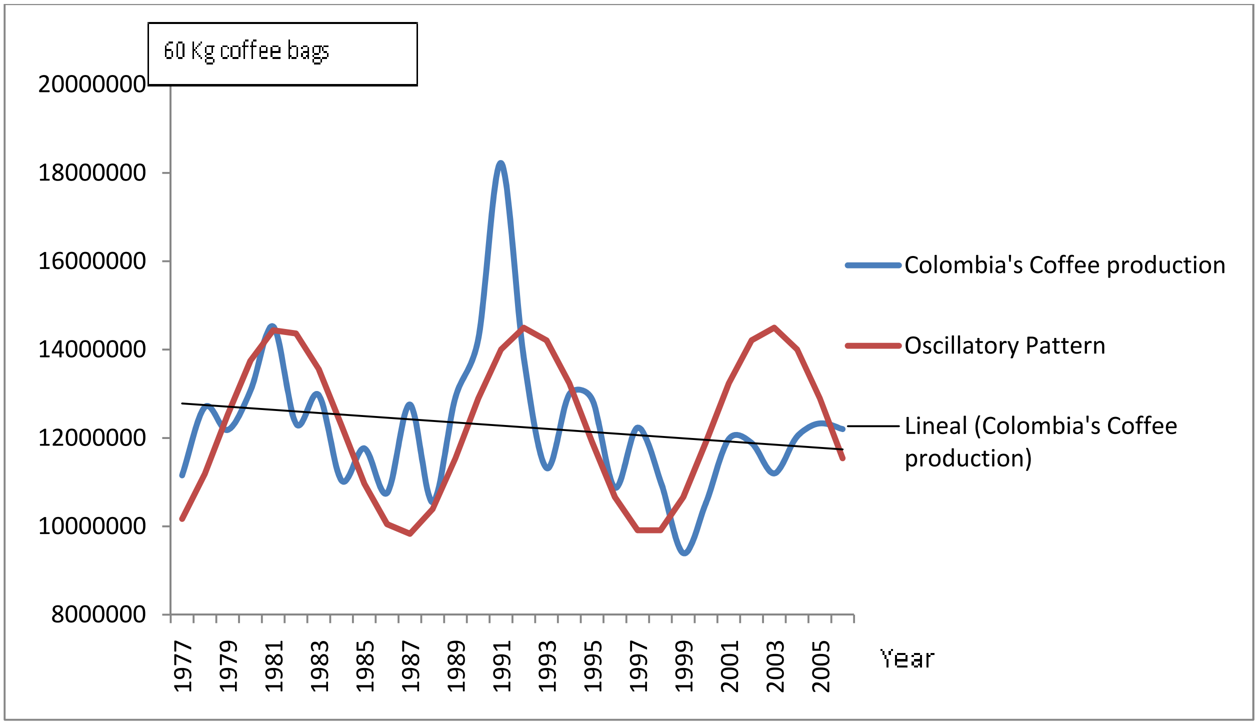

Figure 9. Comparison of estimated trends with the original data.

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One can see in Figure 5., Figure 7. and Figure 10.what we mentioned before about the difference between the cycles in prices and production. For example we can observe in Figure 10., production was at its maximum around 1981 and 1991. On the other hand if we observe Figure 2., we see how price was at its minimum level around those years. So it is clear how both price and production are unstable and they both have cycles of 8 to 11 years amplitude.

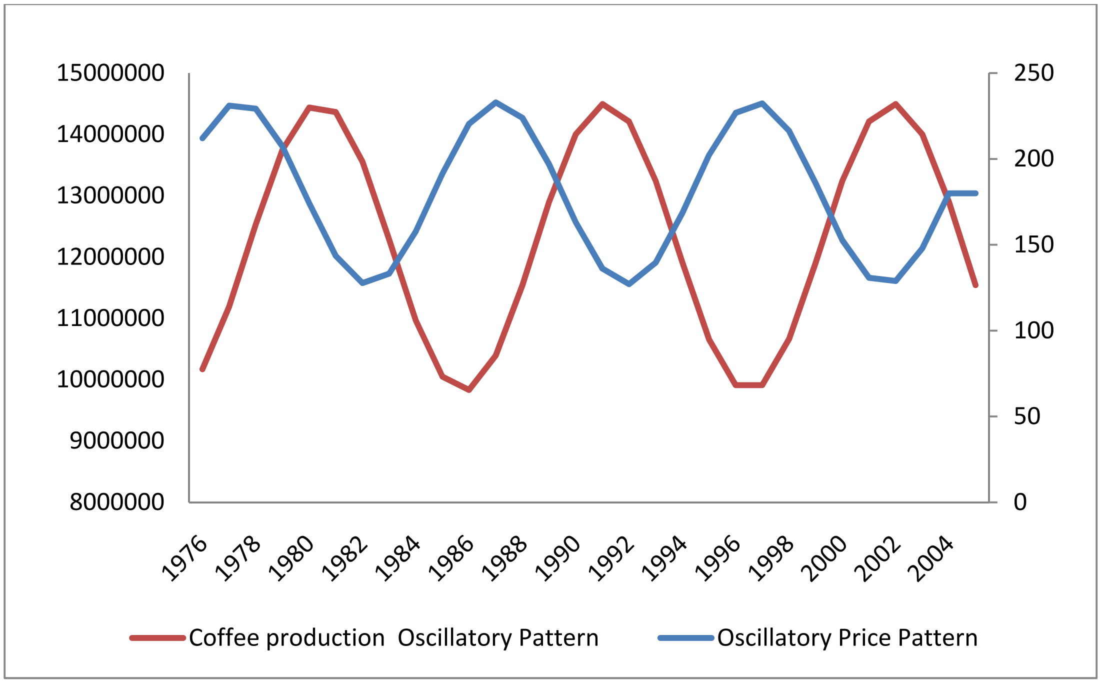

Figure 10. Filtered data, comparison of coffee production and Price oscillatory patterns

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It is important to understand the dynamics involved in this problem, this will help the process for the decision and policy makers, since a better understanding of how the cycles are generated internally promotes the developing of more appropriate stabilization policies in the future. We are going to suggest a structure that might reproduce the problematic behavior described above. From the graphs we can infer the existence of cycles in both Colombian coffee production and its price. And now that we have simplified the data series to create our reference mode, we can move to the next step on modeling: Formulating our Dynamic Hypothesis.

4 Dynamic Hypothesis

In our previous section we described and showed our Reference Mode (RM), which is the behavior we are looking to replicate. In this chapter we introduce our theory that intends to explain why this problem is occurring. First we give a narrative description of our dynamic hypothesis, then we talk about the foundations of our theory (General structure of oscillations) and describe the structure(s) that could cause the oscillations in Colombia's coffee sector showing a general view of the problem, to continue then with a more detailed explanation of our hypothesis and its representation in a Stock and Flow diagram.

4.1 Discussion

There are two main sides involved in our problem: Demand side and Supply side. The interaction between the two sides is the cause of the oscillations. Each side is trying to adjust inventory to a desired level.

On the demand side: depending on the level of price consumers will decide how much coffee to buy (average consumption). Price could have a positive or negative impact on average consumption. If price is too high consumers will prefer to buy coffee substitutes and the opposite will happen at low price. This means price will determine the rate at which coffee inventory is depleted. Finally, we consider that the level of inventories will determine, in part, the price. When inventories are too high (compared with demand) price will tend to decrease.

On the supply side: Price will determine the number of desired trees coffee growers would like to have. Nowadays, coffee growers sow new trees when coffee price is at high levels. They compare actual number of trees versus their desired number of trees and sow the difference increasing the actual number of productive trees and therefore increasing production (if demand is lower than production, inventories will also increase). And as we said in the previous paragraph inventories also determine price. To be more precise, price will be determined by the comparison between supply and demand. Normally when there is surplus of coffee (compared with demand) price tend to decline (the opposite will happen when there is deficit of coffee.

4.2 Causal Loop Diagram

In this section we describe the foundation behind our theory and then we illustrate with a CLD what we have expressed in a narrative way in section 4.1.

Oscillations have their origins associated with negative feedback loops with significant delays. As Sterman (2000) portraits it: *"The state of the system is compared to its goal, and corrective actions are taken to eliminate any discrepancies…" "… The overshooting arises from the presence of significant time delays in the negative feedback loop. The time delays cause corrective actions to continue even after the state of the system reaches its goal, forcing the system to adjust too much, and triggering a new correction in the opposite direction"* (p.114) Figure 11. shows this explanation in CLD terms. It also shows how delays can be in any of the links on the balancing or counteracting loop. In the following paragraphs we apply this to the coffee problem.

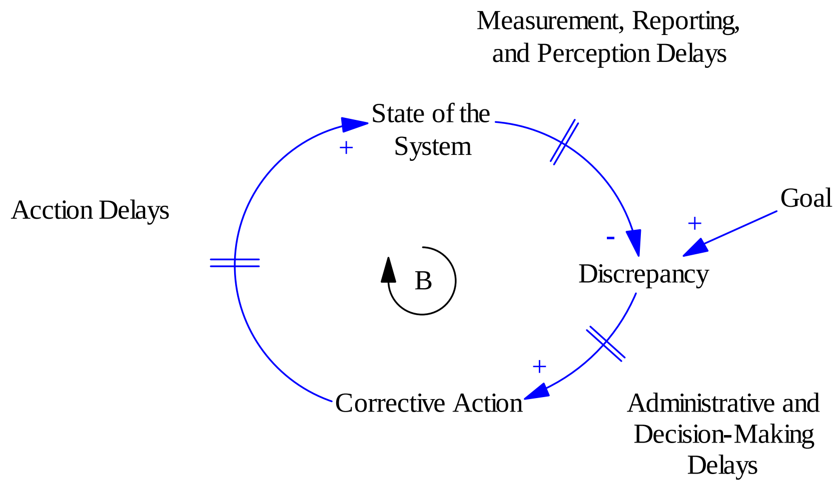

Figure 11.Structure of oscillations

Sterman (2000), Business Dynamics Systems Thinking and Modeling for a Complex World p.114

There are two sides involved in the coffee sector: the demand side represented in Figure 12. as balancing loops called B1 and B3, and the production or supply side represented in the balancing loops named as B2 and B4 in the same figure. The interaction between those loops is the cause of the oscillations in the coffee market, each of these loops is trying to adjust the Colombian coffee inventory to a desired level.

On the demand side (loop B1): when price increases, the average consumption of coffee (demand) decreases, since it will be more attractive to buy coffee substitutes. The demand affects the inventories: when demand for coffee increases the inventories decrease below what they would otherwise have been. Inventories then will determine price, when inventories increase-when compared with demand (supply demand ratio), prices will decrease and vice versa; when inventories are at low levels prices will be at high levels.

Loop B3: When price increases the average consumption of coffee decreases, when average coffee consumption decreases the Supply demand ratio increases and when supply demand ratio increases price decreases and when price decreases the average consumption increases.

Finally on the balancing loop B2 -the production loop- and starting also from coffee price: the higher the price the higher will be the amount of money received by growers ("price paid to growers"), in other words, when prices go up the portion of it that goes to the farmer also increase and the opposite happens when prices go down, and then growers receive a lower portion of the market price. This change in price paid to growers will influence then the expectations of the coffee growers; the higher the actual price paid to growers the higher the expected price by growers. Higher expected price leads to an increase in investments which in the future mean higher capacity, in other words, an increase in production. When capacity increases, Colombian coffee inventory increases above what it would otherwise have been. Finally, to close the loop, higher inventories cause a decrease of price below what it would otherwise have been.

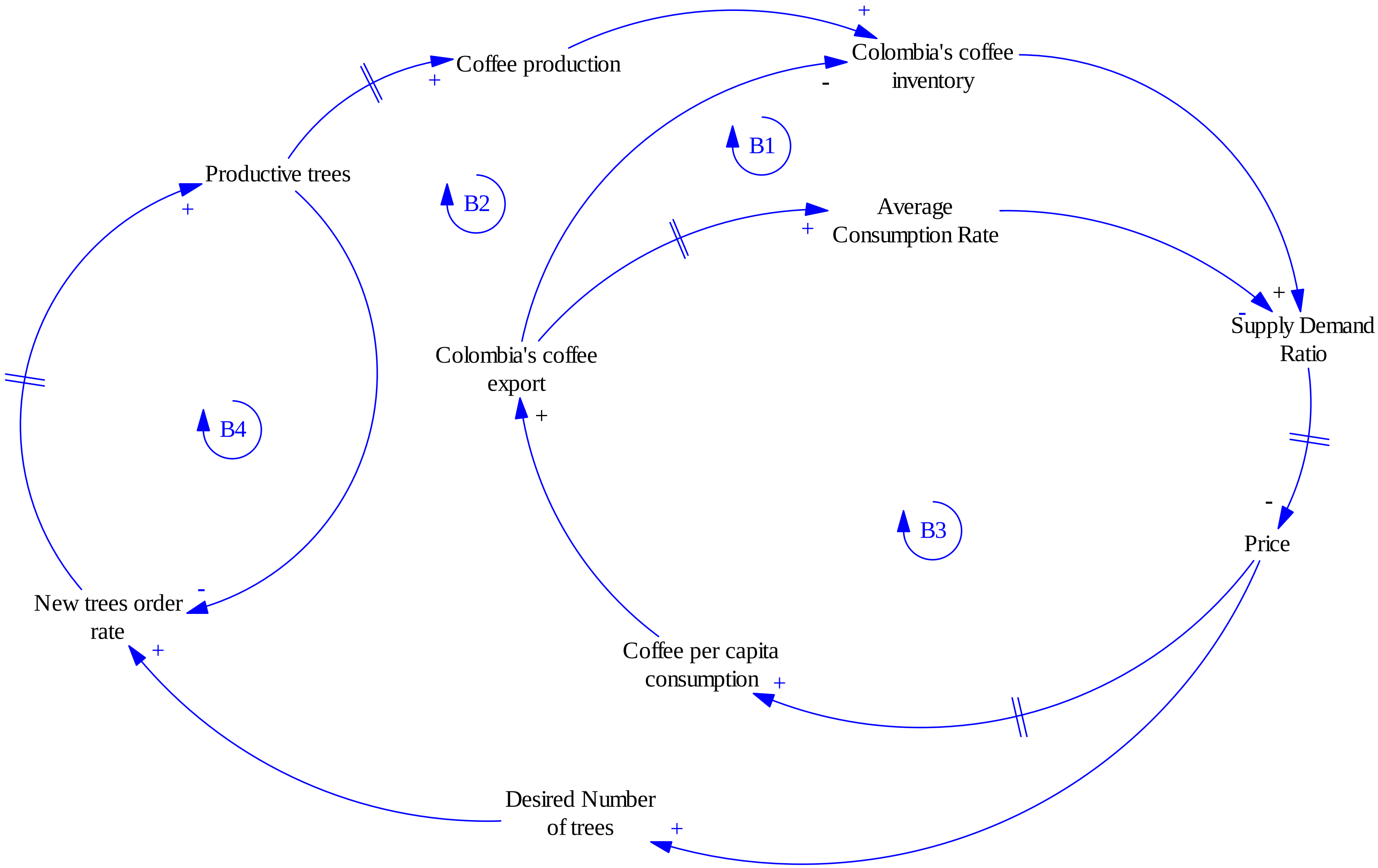

Figure 12. Causal Loop Diagram

We have explained our hypothesis in the simplest possible way. Figure 12.In the following paragraphs we make a bridge between our dynamic hypothesis and the description of the Colombian coffee sector model by analyzing each of the loops we showed in the previous figure (B1, B2, B3 and B4).

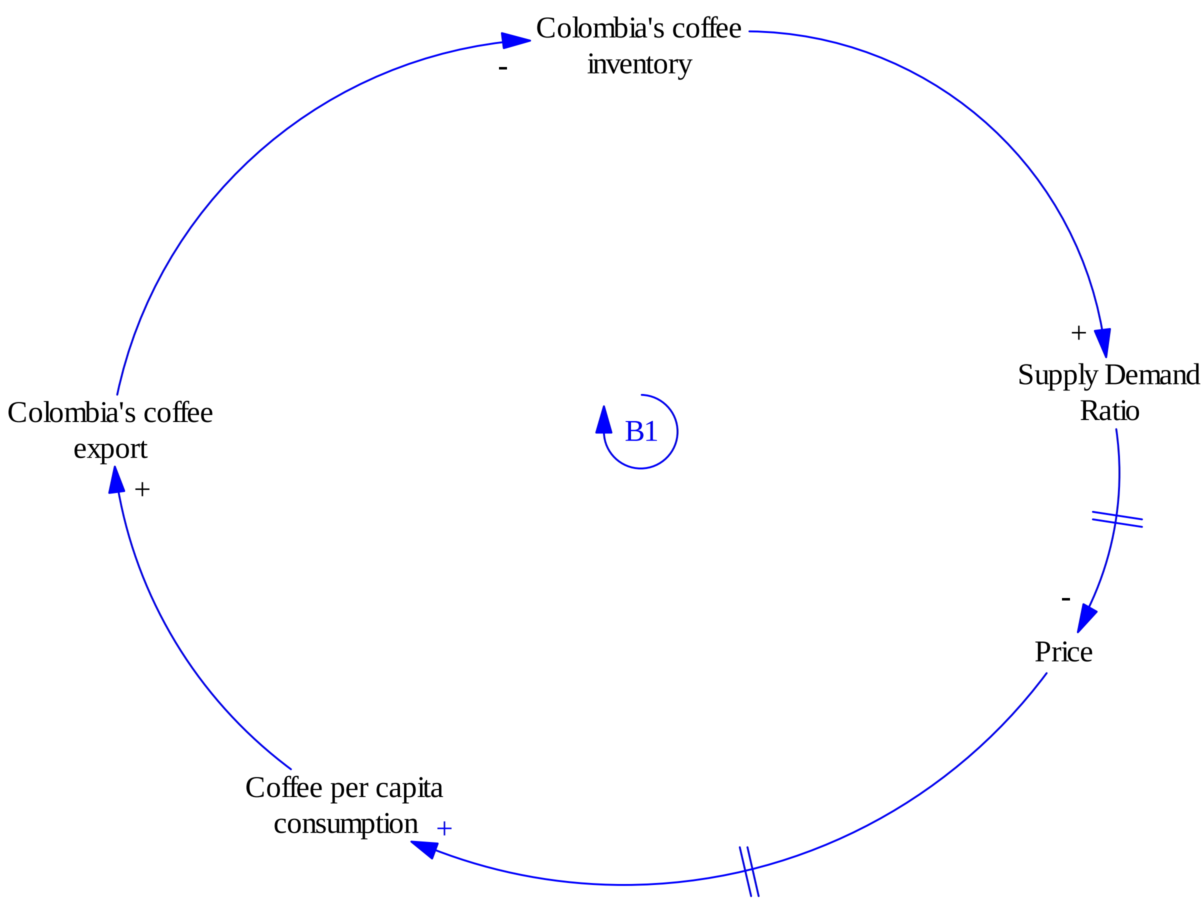

Figure 13.B1 Demand loop

Starting from Colombia's coffee inventory on the upper side of the loop; the higher the Colombia's coffee inventory levels the higher the Supply Demand ratio[12]. The supply demand

[12] The supply demand ratio compares the amount of coffee supplied and the one needed. When this ratio is one, demand and supply are equal. When this ratio is lower than one is because supply is smaller than demand (deficit

ratio is also affected by the average consumption rate (demand for coffee). Now the higher the S/D ratio the lower will be the price. At low prices the equilibrium per capita consumption (the equilibrium between price and demand) will increase, in other words at low prices it becomes more attractively to buy coffee than coffee substitutes so the higher the price the higher the coffee per capita consumption. The higher the per capita consumption the higher will be the exports and, the higher the exports, Colombia's coffee inventories will be lower than otherwise they would have been.

Figure 14. displays loop B2. In this loop we see that an increase in Colombia's coffee inventory will bring the coffee prices to a lower level than otherwise they would have been. At low prices the expectation of the growers will be lower and they will desire to have a lower number of productive trees. The lower the desired number of productive trees the lower will be the difference between the actual number of trees and the desired number of trees so the new trees order rate will be lower than otherwise it would have been e.g., the lower the desired number of trees the lower the new trees order rate and therefore the number of productive trees will be lower than otherwise it would have been, and this will cause a decrease in the coffee production. Finally a decrease in the coffee production will make Colombia's coffee inventory smaller than otherwise it would have been.

of coffee in the market) and that makes prices to go up. Prices will go down if this ratio is bigger than one (that is supply higher than demand)

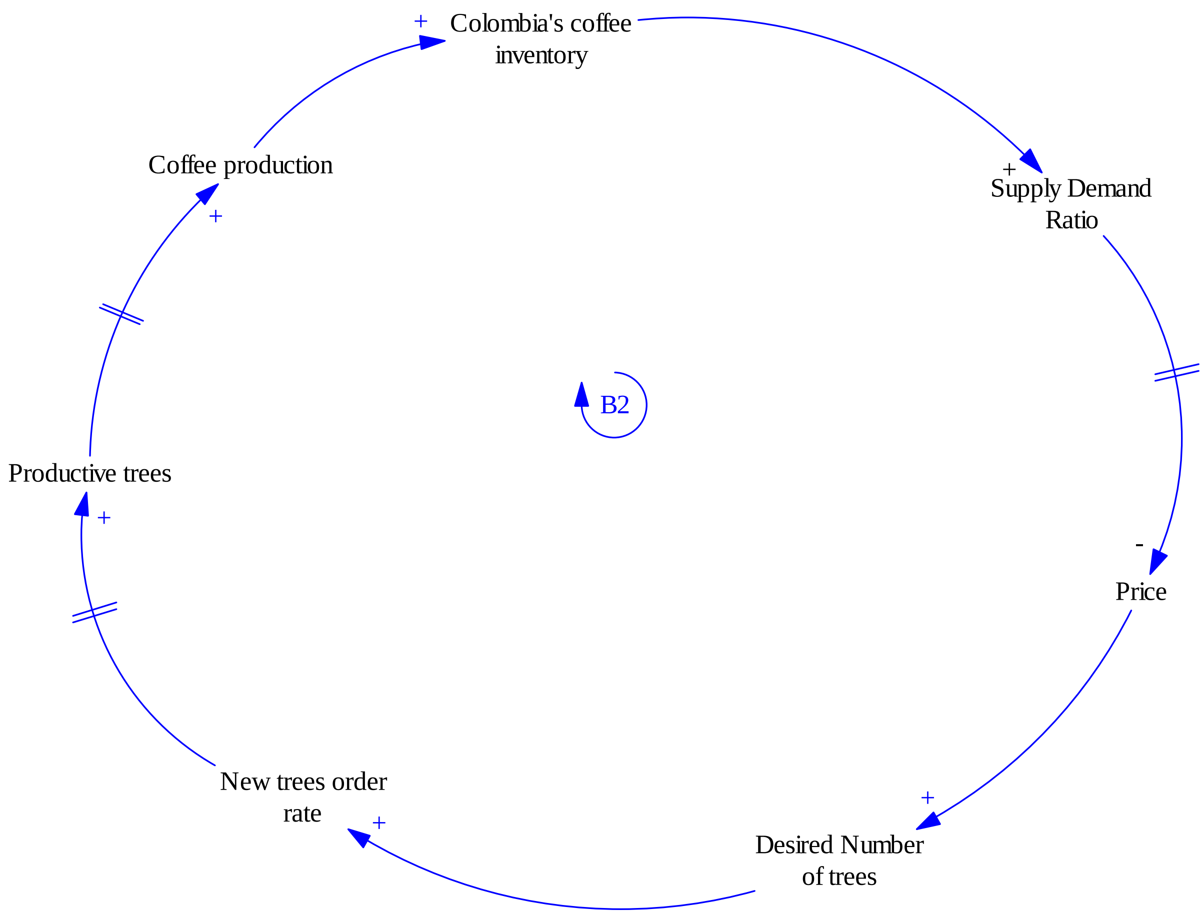

Figure 14.B2 Supply loop

B3 in Figure 15. is similar to loop B1 (demand loop). We have already explained how the supply demand ratio affects price and how this affects the coffee per capita consumption; the lower the coffee per capita consumption the lower Colombia’s coffee exports. At low levels of exports the gap between actual and average consumption will be lower than otherwise it would have been. The lower the gap the lower will be the average consumption rate (Perceived demand).

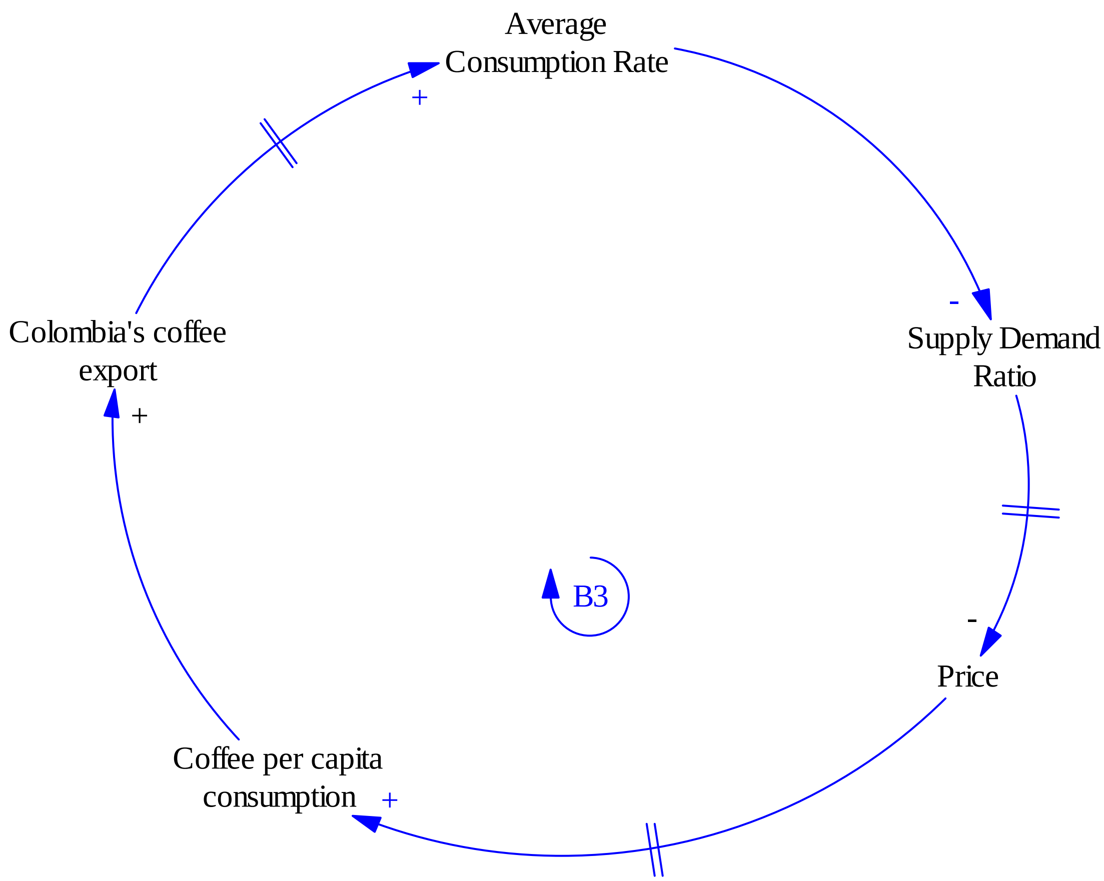

Figure 15.B3 Demand expectations

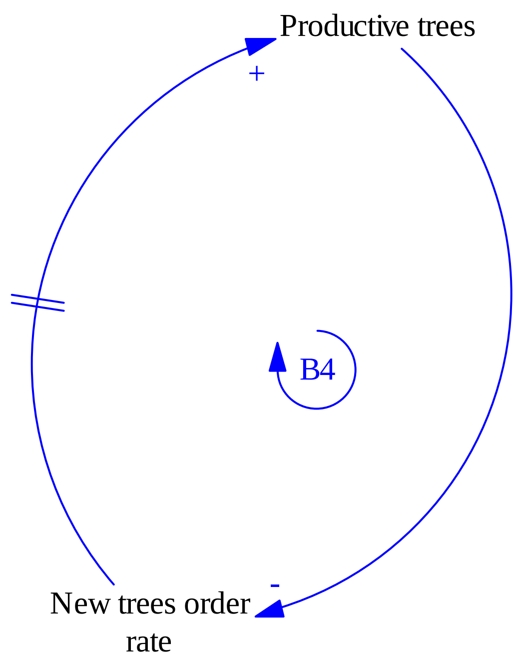

Figure 16. B4 Capacity acquisition loop.

Loop B4 shows the Capacity acquisition process. Trees gap, as we explained before, is given by the desired number of trees (calculated based on expected price by growers) and the actual number of productive trees. The higher the actual number of productive trees the lower the gap. The lower the gap the less new trees will be planted and the lower the number of trees that are added to productive trees will be. The lower the addition of new trees to productive trees the actual number of productive trees would be lower than otherwise it would have been and therefore the amount of coffee that can be produced (capacity).

We show in the previous figures how each of the loops, described earlier in this section, interacts with each other. We based our hypothesis in the assumption that price is always being adjusted by Supply and Demand. Those adjustments are not exact and they tend to surpass the equilibrium point mainly because of the time delays, e.g., the time it takes for either the information to be received, or data to be measured and reported, or the corrective actions to be taken.

After explaining the dynamic hypothesis we would like to point out that there might be other explanations, like the business cycle, for this problem to occur. It might be that not all of the cycles are explained by this hypothesis but even in the presence of business cycle or a partial explanation of the cycles by this hypothesis, there could be a better performance if one understands how the system behaves.

4.3 Stock and Flow Diagram

What we have explained in the past two sections can also be illustrated in stock and flow diagrams. Here we show all the structure of our model and explain the equations we used to formulate our model. Before showing the stock and flow diagram we present some characteristics of our model like its boundaries.

4.3.1 Boundaries:

Longitudinal: we simulated 28 years starting from 1977 till 2005 to compare the results of the model with our reference mode. In the last chapters we ran it from 1977 to 2037 (enough time in the future to capture the possible effects of different policies)

Horizontal: The coffee price is determined by the interaction of some variables; here we will clarify which variables were considered as relevant to include in the model, and to do so we use a model boundary chart. A boundary chart will help us to clarify the scope of the model. We list the key variables and classify them into endogenous ("arising from within" the model), exogenous ("arising from without") and those not included in the model

Endogenous	Exogenous	Excluded
Colombia Production Rate	Consumer Population	RW coffee production
Colombia's Coffee Inventory	Colombian Consumer Population	Retail Price
World Coffee Price (Mild Arabicas)		Domestic Price
Coffee Trees		Robusta coffees prices
Coffee Per Capita consumption		Production costs
Expected Price by growers		Robusta coffee production and

		inventories
		Weather variables

Table 1.Model Boundary Chart

Exogenous Variables:

Consumer Populations: For simplicity and because is not inside the aim of this research we considered consumer population as an exogenous input. We are not interested on the dynamics of Colombia and/or Rest of the World Populations. To model these two variables we used historical data.

Excluded Variables:

Rest of the world coffee production: We will just consider the inventories of Mild arabicas coffees. We do not intend to create at this stage a world coffee market model; we are only interested on Colombia's coffee market.

Retail Price, Domestic Price and Robusta coffees price: We considered only one price. We assume that for the long term dynamics the differences of these prices will be unimportant. [13]

Weather: We consider that the cycles can be explained endogenously without any need of natural events; weather might help to amplify or reduce the cycles though.

4.3.2 Major Assumptions

Models are just a simplified representation of the real world and so they depend on certain assumptions. Here are the several assumptions were adopted:

- Demand: Only one form of demand that includes the demand from the different actors of the coffee sector (Roasters, Inventory holders, etc.). We did differentiate between national

[13] Each price is different, domestic price for example is the price paid either FNC or other buyers in Colombia when the coffee is going to be used to satisfy Colombia's demand, Robusta coffees price refer to the price of this type of coffee.

and international demand. We are mainly interested in the international demand, e.g., Colombia's coffee exports, because that is where most part of Colombia's coffee goes.

- Future markets: we did not include future markets in our model. Future market may not be essential components of the model since the behavior we are trying to explain existed long before the use of future markets in the coffee sector.

- Prices: in the actual structure of the coffee market there is more than one price for coffee, e.g., price paid to growers, price received by roasting companies, etc. For simplicity we considered just one price since for the long term dynamics the differences of these prices will be unimportant. The price we used can be compared to the ICO indicated price for Colombian mild Arabica

- Population: we use historical and exogenous projected data for Colombia and Rest of the World population.

- We did not find enough data on the productivity of the trees, and number of trees planted. So we made some guess-estimations in this aspect.

- Acquisition of new trees to increase capacity: We assume that the coffee growers will decide to increase their productive capacity when prices are at high levels and they decide to decrease it (or not renew it) when prices are at low levels. This part should be tested in future researches to understand how coffee growers decide on this subject.

- We assumed the yield per tree to be constant over time, e.g., the trees produce always the same amount of coffee.

Although the above assumptions limit the scope of the research, they will not defeat the purpose of this project; moreover the assumptions will reduce the size of the model making it simpler and easier for other users to understand it.

4.3.3 Main Stocks and Flows

We will present the simplest structure that will be able to replicate cycles to then start disaggregating our final model.

Based on DL Meadows (1970) and Sterman (2000) we came up with this basic structure for the Colombian coffee market. This is a highly aggregated version of the model we present further on this chapter. The idea is to present and explain the main parts of the model and so proceed to analyze it in a more detailed way. This will help us to do a transition between our CLD explained in section 4.2 and our final stock and flow structure.

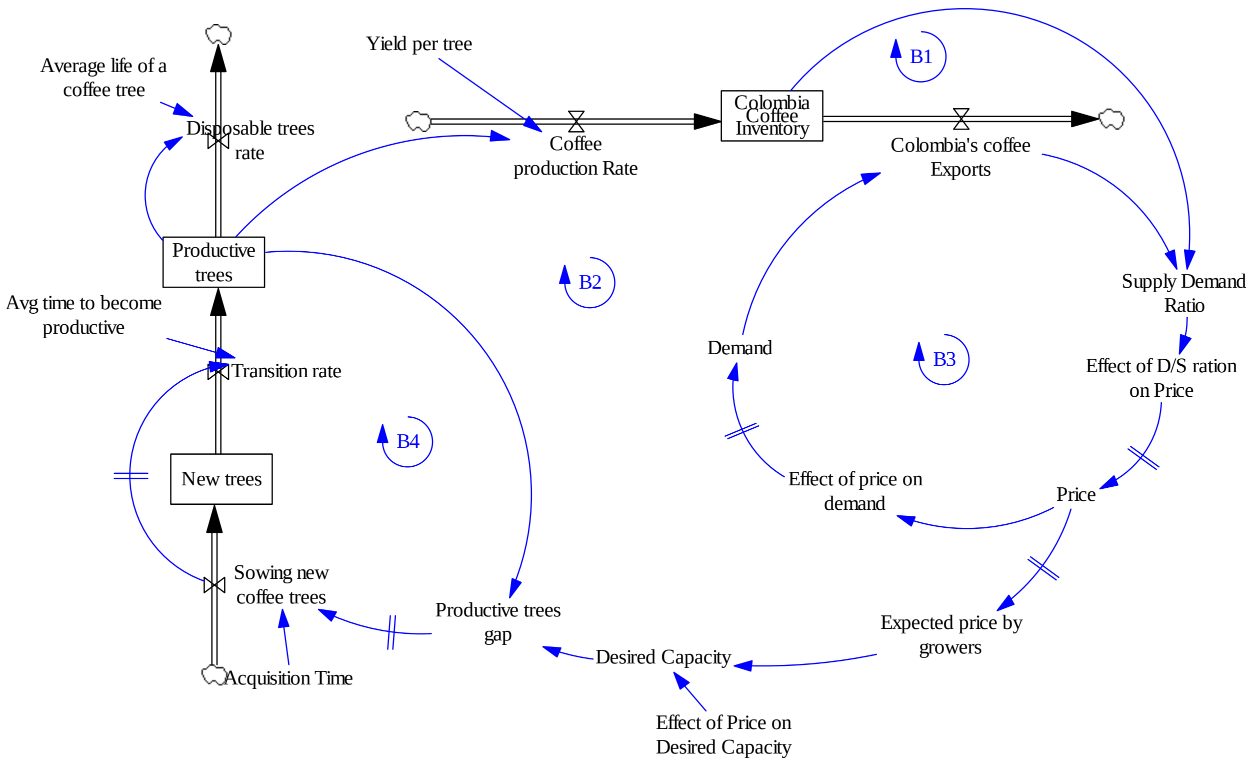

Figure 17. Basic Structure of the Colombian coffee Market.

One can see in Figure 17. the main four loops we described in the previous chapter and its structures. Those loops can be disaggregated into some sectors explained in the coming paragraphs. Mainly we have these sectors: Production and Inventory of coffee, Coffee trees structure, desired number of trees, Demand and Price. On the upper part of Figure 17., is the supply chain for the coffee market, e.g., production of coffee and inventory. The inventories are increased by the production and decreased by coffee consumption. On the left side, we found the capacity production; increased only by the sowing of new coffee trees and decreased by the depreciation of the productive trees. We mentioned previously, that the cycles were originated because there is a permanent adjustment between Supply and Demand. Basically, those structures we mentioned here are the responsible for such adjustment. In the following paragraph we try to explain how.

The coffee price will affect, among others, two things; on the one hand the attractiveness of the growers to invest on new coffee trees and the demand for Colombian coffee. Let’s discuss first the demand side. At relative high prices the consumers will prefer to buy other types of coffee like Robustas or other mild arabicas, so demand for Colombian coffee will decrease. This part is marked in loop B3 in Figure 17.. One can see how the link between effect of price on demand and demand is marked with a line. This line represents a delay, because usually it takes time for the consumer population to change from one type of coffee to another one or to change to a substitute (in some industries cacao is a substitute for coffee). So price will make demand increase or decrease. On the capacity side, at high prices coffee growers will see opportunities to save more and invest more in new trees and therefore increase capacity. The opposite will happen at low prices, there is not enough resources or attractiveness to invest on trees (sow new trees or renew of the old ones) to build more capacity. Now the price is set depending on both inventory (kg of coffee and which as we said is increased by actual productive capacity), and demand (kg of coffee consumed per year). The permanent adjustment of the three variables (Inventories, Demand, and Price) and the delays in this market cause therefore oscillations. The perception delay to perceive the actual price, by both growers and consumers, and compare it with other types of coffee or the substitutes. The material delay to sow new trees and the time needed to harvest those new trees, etc. We try to make this reasoning clearer by explaining the full stock and flow diagram.

In the following paragraphs we use stock and flow diagrams to describe the structure of our model. We show step by step how we build the model and we also describe the feedback structures that were needed to replicate the reference mode, defined in section three. We elaborated this model based on the generic structures created by DL Meadows 1970 and Sterman 2000, and adapted those for the Colombian coffee sector.

4.3.3.1 Inventory

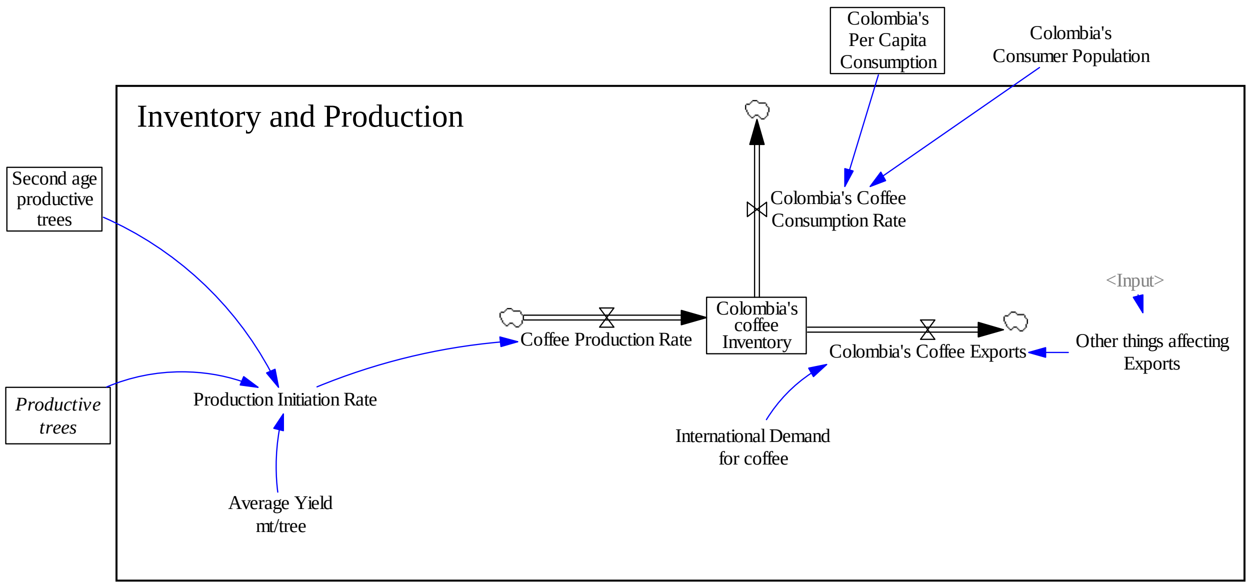

Figure 18. Colombia’s coffee inventory Stock and Flow structure

Figure 18. shows the stock and flow structure for Colombia’s coffee Inventory and the inputs from other sectors (represented outside the box). Below we find the explanation for each one of these variables and the relationships among them.

Colombia’s Coffee Inventory (stock) represents the actual amount of coffee that the Colombian coffee federation holds in their warehouses. It’s only increased by the coffee production rate of the country and decreased by both the internal consumption rate and the consumption rate worldwide, e.g., demand.

Colombia’s coffee Inventory = Integral (Coffee production rate – Colombia’s coffee consumption – Colombia’s coffee export, Colombia’s coffee inventory$_{t0}$)

The Production rate is a third order delay function. The production delay refers to the 2 or 3 months it takes to collect the coffee beans, classified them, dry them and sometimes toast them, and transport them (to FNC warehouses or to private buyers). Colombia has crop all year round although there is one big crop (main crop) and few small crops during the year.

Coffee Production Rate = Production Initiation Rate

The Production Initiation rate is determined by the actual number of productive trees (Productive trees and Second age productive trees) and average yield of the trees.

Production Initiation Rate = Productive trees*"Average Yield mt/tree new trees" + Second age productive trees*"Average Yield mt/tree old trees"

The other two flows are Colombia's coffee consumption rate and Colombia's coffee exports both outflows.

Colombia's Coffee Consumption Rate = Colombia's Per Capita Consumption*Colombia's Consumer Population

Colombia's coffee export is the demand for Colombian coffee which has pretty much the same form as the Colombia's coffee consumption rate. The difference, though, is that the per capita consumption of importing countries is not a constant and varies depending on the coffee price.

Colombia's Coffee Exports = Demand for coffee

Although this structure alone cannot produce the behavior described in the previous section, it does play an important role in the behavior of the market, since both production and consumption sectors are always trying to maintain inventories at a desired level (DL Meadows, 1970). The level of Inventories will affect the level of *Price*, in the sense that the bigger the inventory of coffee the lower the coffee price than it otherwise would have been. But inventories are not the only variable affecting the price. Let's add more structure to the model to clarify this point.

4.3.3.2 Demand

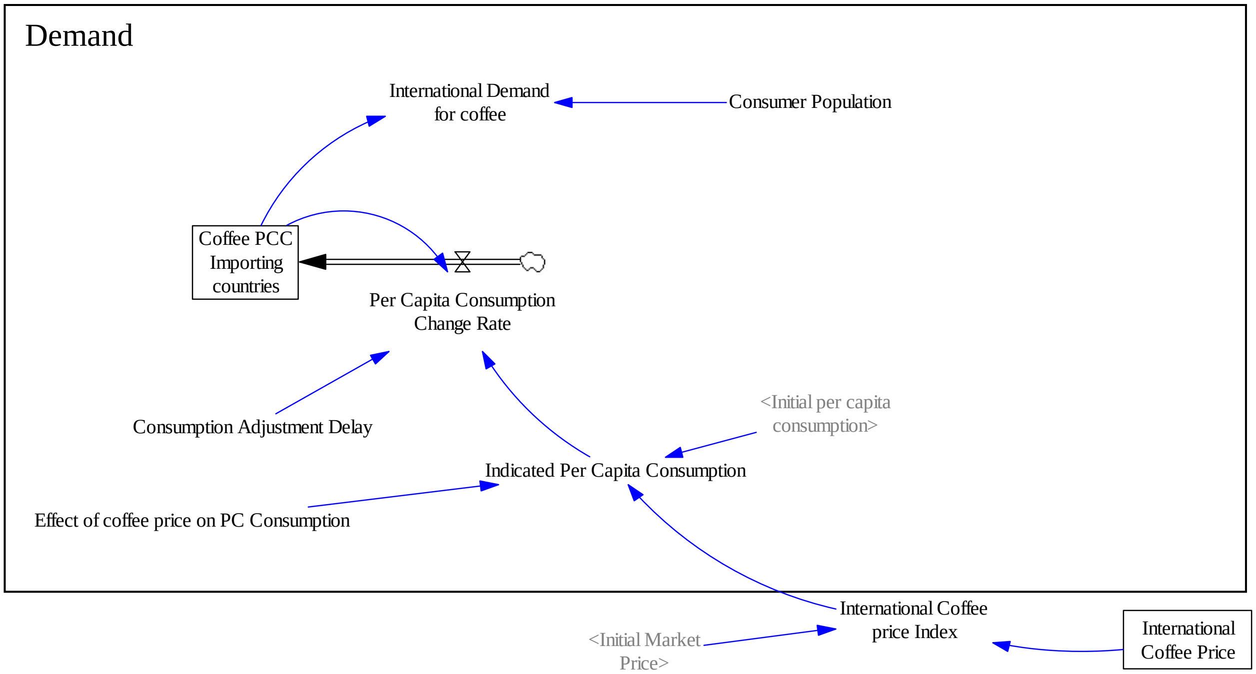

Figure 19. Demand, Stock and flow structure

As we mentioned before the demand contains the required coffee by the different actors in the coffee sector (roasters, inventory holders, other industries, etc). Figure 19. shows the whole stock and flow structure for the international demand of Colombian coffee. It also shows the input from other sector, more specifically, price.

The demand for coffee is determined by the coffee per capita consumption in importing countries and the consumer population for Colombia's type of coffee, e.g., the potential demand. We treated the consumer population as an exogenous input to the model and used historical data for the consumer population in the importing countries.

Demand for Coffee = Consumer Population*Coffee PCC Importing countries

Coffee per capita consumption refers to the amount of coffee a single person will have in a year and it can be represented as a first order information delay since it will take some time before the consumers realize the increase or decrease in price and actually change their preferences.

Depending on the price for coffee the consumption will increase o decrease, when price increases demand tends to decrease. The equation for Coffee PCC in importing countries is:

Coffee PCC Importing countries = Integral (Per Capita Consumption Change Rate, Coffee PCC Importing countries $_{t0}$)

The net change rate is given by the equilibrium of the per capita consumption, the current coffee per capita consumption and the consumption adjustment delay; which is the time it takes for the consumer population to adjust their preferences or the time it takes for a company to change to a substitute. So basically it compares the indicated with the actual consumption and adjusts the difference over time.

Per Capita Consumption Change Rate = (Indicated Per Capita Consumption-Coffee PCC Importing countries)/Consumption Adjustment Delay

Indicated per capita consumption, as its name states, is the amount of coffee a consumer will buy given the price, e.g., the indicated demand at certain price level.

Indicated Per Capita Consumption = Initial per capita consumption*Effect of coffee price on PC Consumption (International Coffee price Index)

The effect of coffee price on PC consumption is defined as a non linear function, and it is shown in the next figure. We modeled it using the *lookup* or *table* function. The input for this table function is the relative International coffee price defined as:

International Coffee Price Index = International Coffee Price/Initial Market Price

So the International Coffee Price Index is a dimensionless variable that represents the increment or decline of the international coffee price when compared to an “initial market price”. It is worthy to mention, that this initial value is not the price of coffee during 1976 but an average value.

The output of this lookup function is also a dimensionless effect which multiplied by the Initial per capita consumption will give us the indicated per capita consumption. The effect has a downward slope. The effect is one (1) when International coffee price equals the Initial market price, this means there is no effect and the consumption will be equal to the initial per capita consumption. On the extreme condition that price of coffee is equal to zero and, therefore Relative International Coffee Price will be zero, the consumption will be 200% bigger. On the opposite side when the International Coffee Price is three times the Initial Market Price, the equilibrium of per capita consumption will be reduced 75%. To summarize, high relative price levels (actual price higher than initial market price) will tend to cause a decrease on coffee consumption (right part of the graph). As international coffee price moves towards the initial market price, coffee consumption will start moving towards the no effect point described above; and when international price goes below the initial market price the coffee consumption starts increasing rapidly at first and then slowly until it stabilizes forming an S-shaped curve. These values are just estimates; more research is needed in this area.

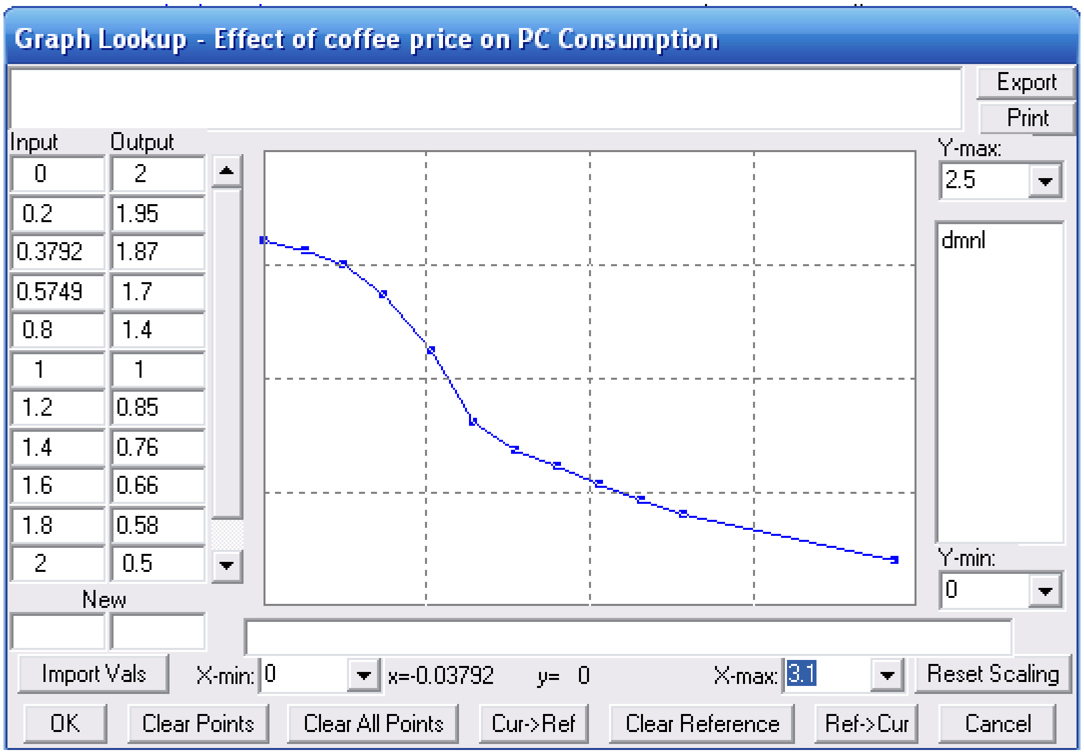

Figure 20. Effect of coffee price on PC consumption

4.3.3.3 Price

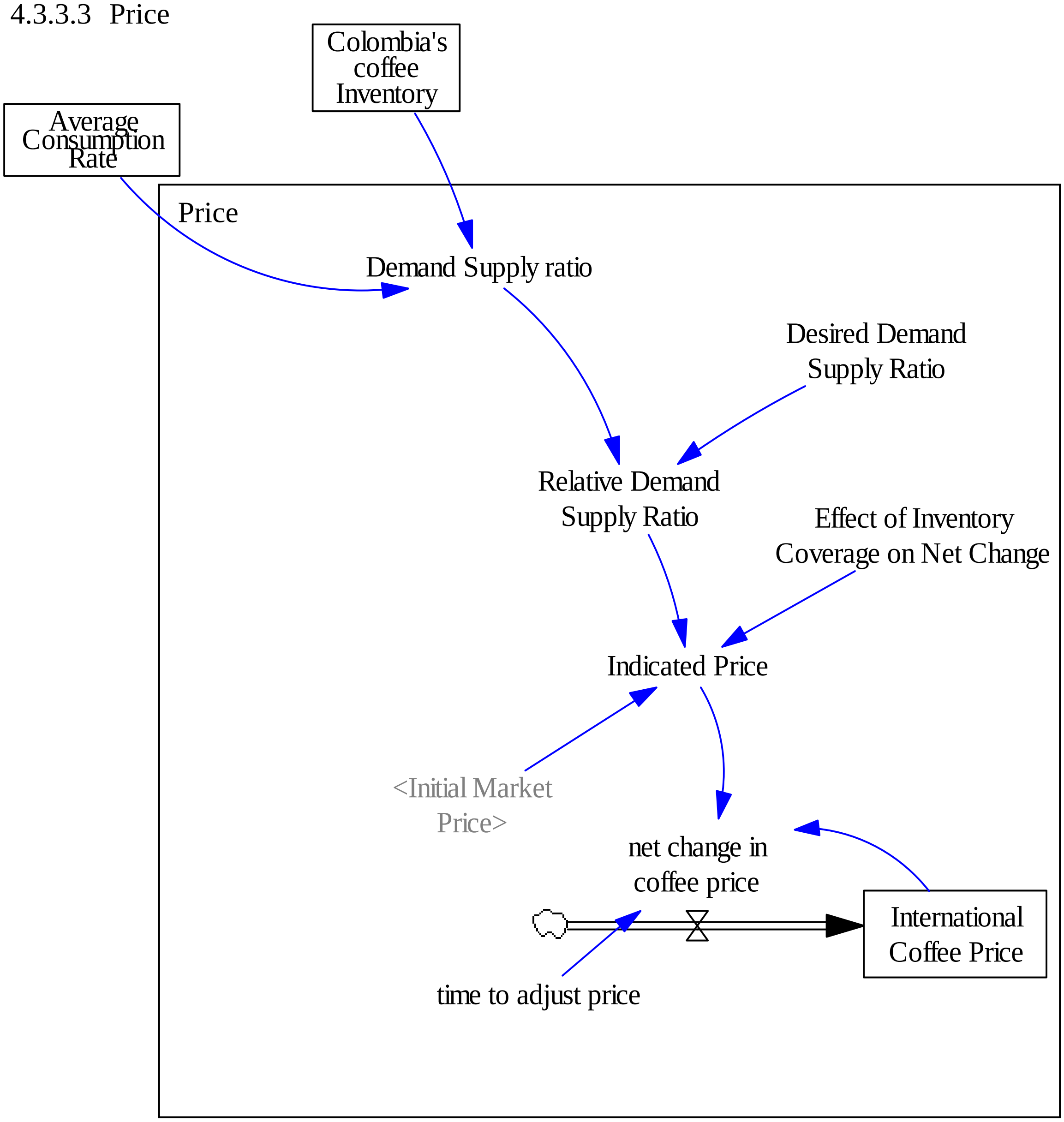

Figure 21. Expected Consumption structure

Previously we said price does not adjust immediately to changes in other variables. It takes some time before the price reaches its "equilibrium value" depending on the supply demand ratio. In order to capture this, we used an information stock to model the International Coffee Price for Colombian coffee. This stock has only one way to change; that is through its netflow "net change in coffee price"

International Coffee Price = Integral (net change in coffee price, initial coffee price $_{t0}$)

The actual coffee price (stock) is compared with the indicated price and the difference is adjusted over a period of time. The period of time is defined as the time needed to correct the price; we defined it here as 2 months.

Net change in coffee price = (Indicated Price-International Coffee Price)/time to adjust price

Indicated price refers to the price that the coffee should have, given the levels of inventories and demand. It differs from the International coffee price, because as we mentioned before, these types of changes do not happen instantly.

Indicated Price = Initial Market Price*Effect of Inventory Coverage on Net Change(Relative Supply demand Ratio)

The indicated price is determined using a *table* function. This table function depends on the relative value of the Inventory coverage, here called “relative supply demand ratio”. The table function is shown in Figure 22. and it can be interpreted as follows. When inventory coverage is equal zero prices will increase 3 times the initial market price; when desired inventory coverage is equal actual inventory coverage the price will be equal to the initial price and; when inventory coverage is two times the desired inventory coverage the indicated price should be 10% of the initial market price. From right to left on the graph, when the input (“relative supply demand ratio”) is high (supply demand ratio higher than desired supply demand ratio) the effect is very low, basically because a high value of the variable “relative supply demand ratio” means there is a surplus of coffee, causing a fall in price; as relative supply demand ratio decreases (less surplus of coffee) the effect slowly increases until we reach the no effect point, that is “supply demand ratio” and “desired supply demand ratio” are equal to each other. As relative supply demand ratio continues decreasing the effect increases, fast at first and slowly then until it reaches the highest value (this happens when “relative supply demand ratio” equal zero).

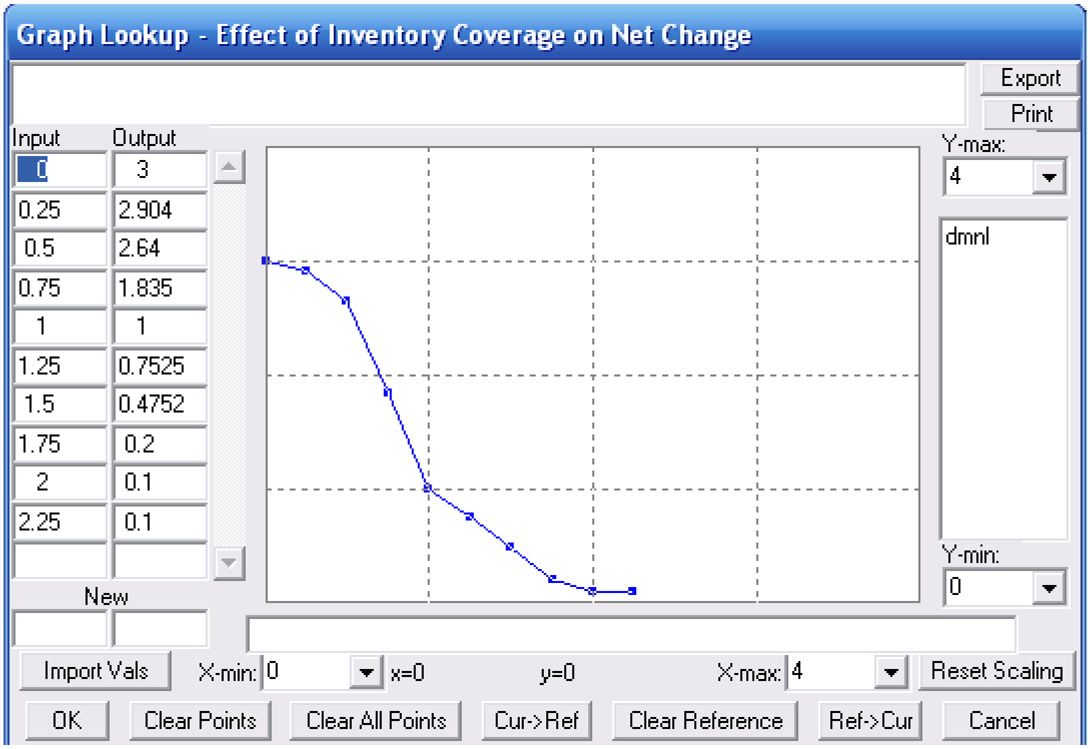

Figure 22. Effect of Inventory Coverage on Net change

The input for this table function is the variable named “relative supply demand ratio”. It is a dimensionless variable that compares the actual vs. the desired supply demand ratio. It could be seen as the difference between what the federation wants to have to cover the demand vs. the real amount of coffee available to actually do it.

Relative Supply demand Ratio = Supply demand ratio/Desired Supply demand Ratio

The desired supply demand ratio is a constant number defined as 10 months approx (this is a personal estimation; nowadays inventories can cover around half a year of demand but there is no certainty whether 6 months is the normal value because 2008 and 2009 were rainy years in Colombia and due to this rainy season a big part of the crop during these years was damaged). The actual value (Supply demand ratio), on the other hand, is defined as the actual amount of coffee available (Colombia’s coffee inventory) over the demand (Average consumption rate)

Supply demand ratio = (Colombia's coffee Inventory)/Average Consumption Rate

So far, we have built 3 sectors: Inventory, Demand and Price. Figure 23., shows these three sectors together. This structure represents what we called in section 4 the demand side of the Colombian coffee market. This structure itself is not enough to produce cycles with the same characteristics as the ones described in previous sections. In the following section we will develop the supply side alone and once this one is complete we will link it with the one we just explained and when both structures are together we expect to reproduce the behavior of the Colombian coffee market.

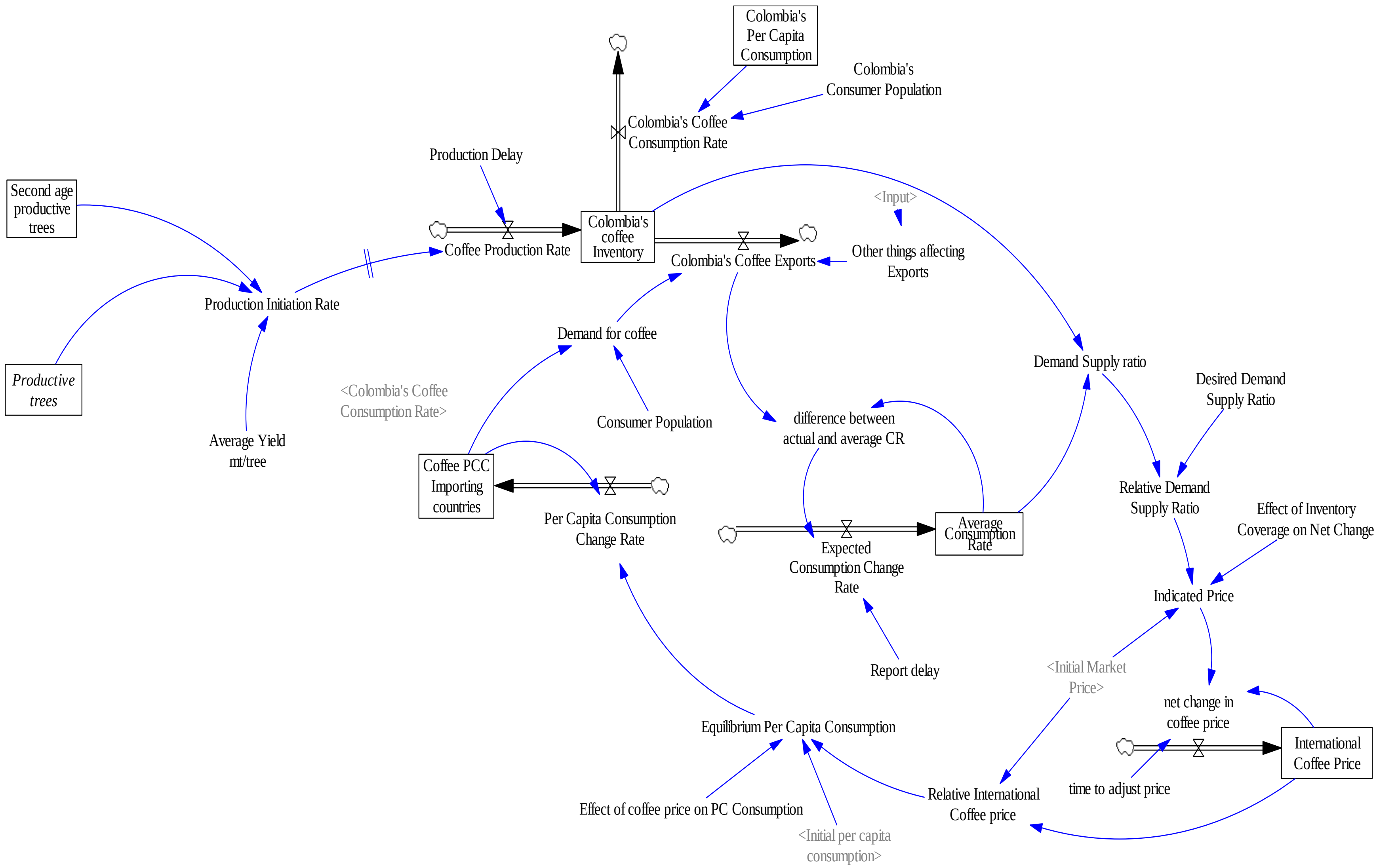

Figure 23. Complete demand side

4.3.3.4 Desired Number of trees

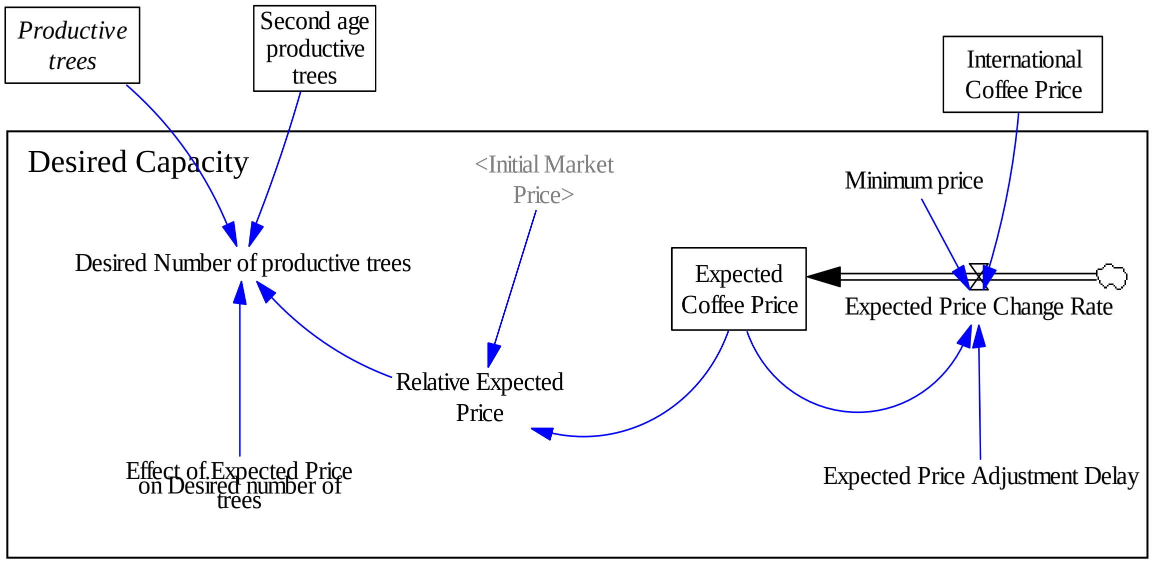

Figure 24. Desired Number of trees

This part of the model represents the desired number of coffee trees of all coffee producers. We assume, producers will increase their number of coffee trees only if they expect high prices of coffee. The structure and all the variables are explained below.

Based on the international coffee price, growers form their expectations about the future price of coffee. We defined this expectation process as a first order information delay since we believe that growers don't adjust immediately their expectations.

Expected Coffee Price = Integral (Expected Price Change Rate, expected coffee price $_{t0}$)

Expected Price Change Rate = (International Coffee Price-Expected Coffee Price)/Expected Price Adjustment Delay

The expected price adjustment delay is the time it takes for the coffee growers to perceive the international coffee price (this could be delay to receive the actual information, uninformed, etc.)

Minimum price: this variable represents the actual policy of the coffee growers' federation. It guarantees that the price will not go below a certain value. So, when international coffee price goes below this value growers adjust their expectations to the minimum price instead of adjusting them to the actual international coffee price. In real life this minimum price is defined every year, based on several variables like; exchange rate, costs of production materials, and others. Here we defined as a constant, considering that the yearly adjustment will not affect the result of the simulation. It is the concept itself, the one we are interesting on to see the impact of such policy.

To calculate the desired number of productive trees we used a nonlinear effect. The input to that effect is a normalized variable called Relative Expected Price. It is defined as the expected coffee price divided by initial market price. It compares the expected coffee price with a reference value (an average coffee price) to determine whether the expected price is higher or lower than the average coffee price.

Relative Expected Price = Expected Coffee Price/Initial Market Price:

The other variables used to calculate the "desired number of productive trees" are: the actual productive trees and second age productive trees. We defined the desired productive trees as a proportion of the actual amount of trees producing coffee.

Desired Number of productive trees = (Productive trees + Second age productive trees)*Effect of Expected Price on Desired number of trees (Relative Expected Price)

The effect of Expected Price on Desired number of trees is shown in Figure 25. It says that when prices are at low levels, coffee growers want to have less productive capacity so they want to decrease the actual number of productive coffee trees and when prices are at high levels they want to increase their actual productive capacity. From left to right on the graph; when the expected price is lower than the initial market price the effect is to have fewer trees (for example, when expected price is 20% of the initial market price, farmers would like to have 50% of the reference number of trees and instead they will prefer to move to harvest other type of goods). As relative expected price increases the effect increases as well, slowly at first and fast then, until it reaches the no effect point (Expected price equal to initial price), at which coffee growers would like to keep the same number of trees they have at the moment. After the no effect point, as the input keeps increasing so does the output (it increases in a decreasing way) until it reaches the maximum value (when expected price is twice the initial market price, the effect is to increase around 30% the actual number of trees)

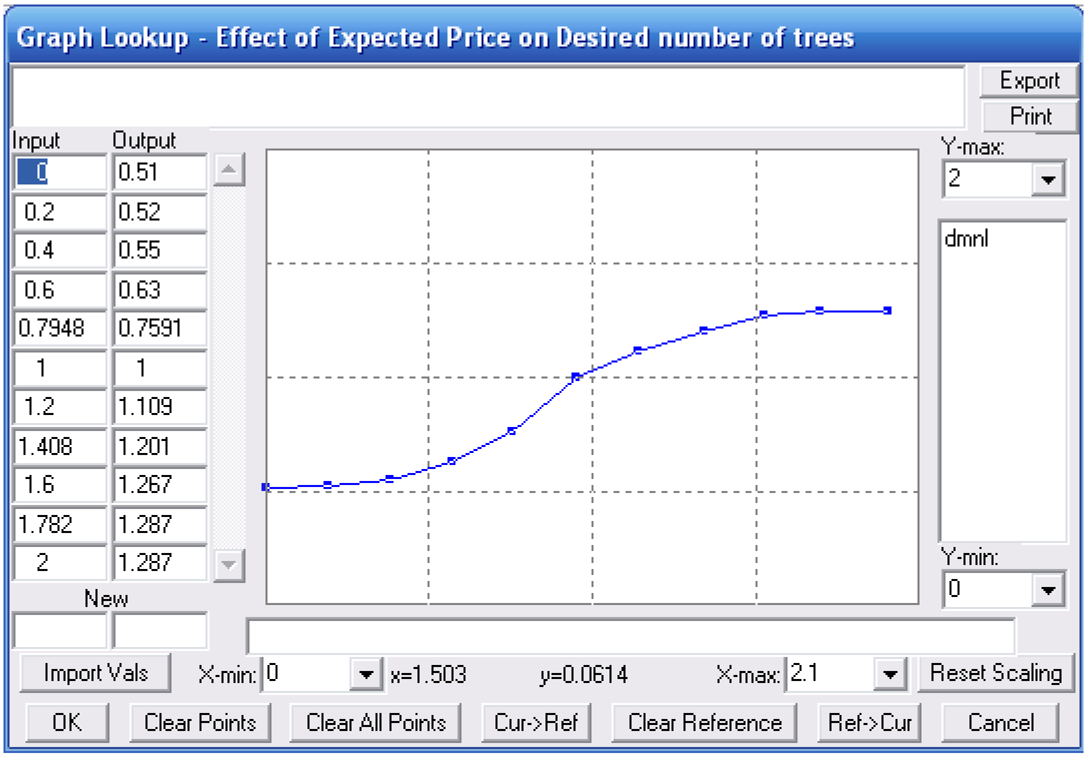

Figure 25. Effect of Expected Price on Desired number of trees

4.3.3.5 Coffee trees structure

Figure 26. shows the trees acquisition structure, its variables and the inputs from others sectors.

The Coffee trees structure sector is represented as a supply chain of trees. The trigger to this supply chain is the decision to sow new trees or not. This decision is based on the difference between desired number of productive trees (defined in the previous section) and the actual productive trees (both Productive trees and second age productive trees). That difference is defined here as the productive trees gap.

Productive trees gap = Desired Number of productive trees-Productive trees-Second age productive trees.

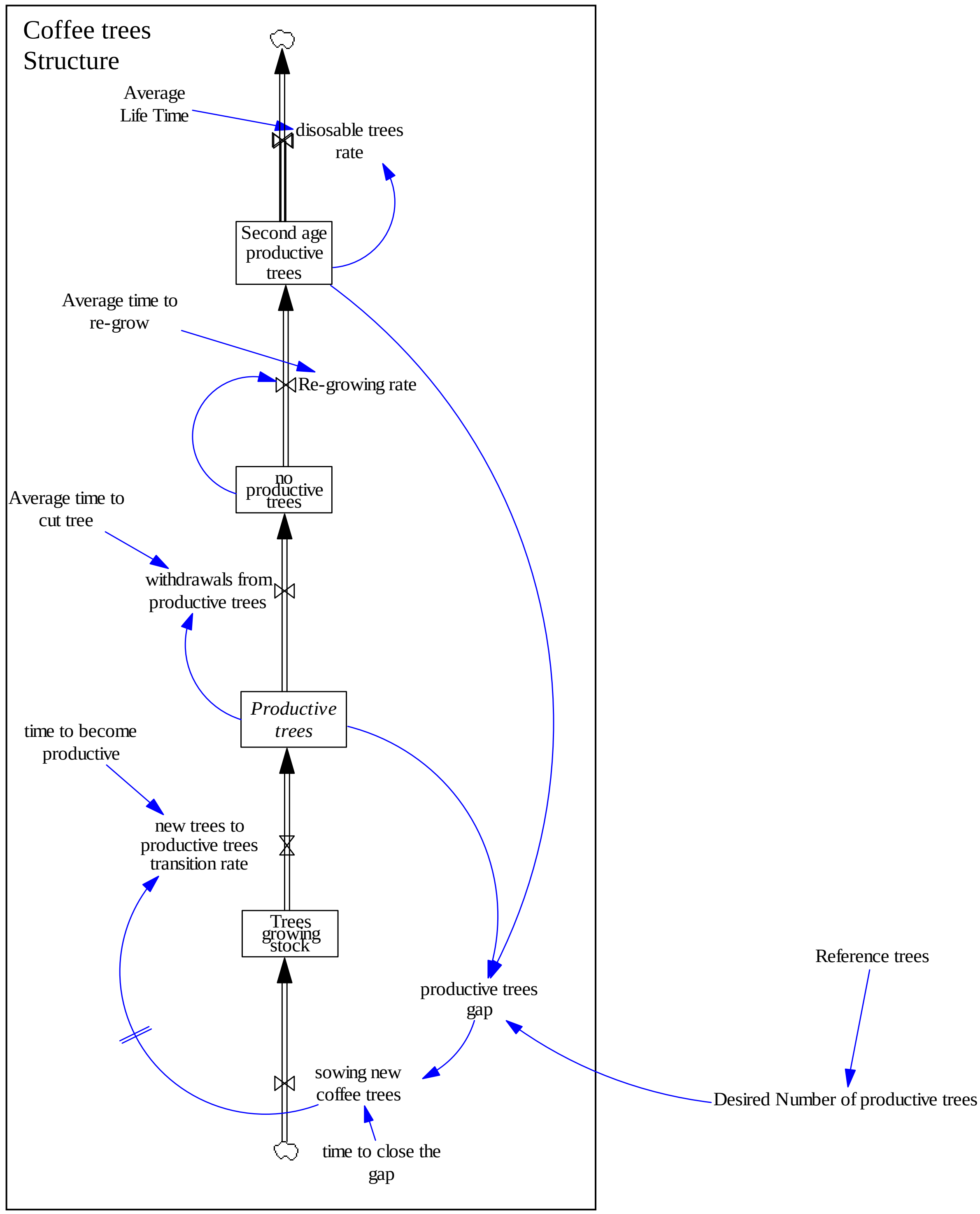

Figure 26. Trees acquisition structure

Based on this gap the coffee producers make the decision to sow or not new trees. We said this gap is normally closed within six months, this is the required time to adequate land, obtain capital, and buy seeds, and so on. We assume that there is no voluntary destruction of trees. If the desired number of trees is lower than the current number of trees, the coffee producer will choose to maintain the actual number of trees instead of destroy the difference, which is why we used a max function in the equation.

Sowing new coffee trees = max (0, (productive trees gap)/time to close the gap)

The seeds need between 2 and 3 years to become productive

New trees to productive trees transition rate = DELAY3 (sowing new coffee trees, time to become productive)

During the 2 to 3 years that require to become productive, the trees stay in the stock of growing tress, which flows are the two previous equations. This stock grows when coffee farmers sow new trees and decreases when the trees reach the productive age.

Trees growing stock = Integral (sowing new coffee trees-new trees to productive trees transition rate, Trees growing stock $_{t0}$)

The second stage of the coffee trees is the productive trees stock, where the trees move once they reach the productive age, and move out when they reach a non productive time.

Productive trees = Integral (new trees to productive trees transition rate-withdrawals from productive trees$_{t0}$)

The trees pass from the growing stock to the productive stock and stay there for 6 years. After this time, the coffee farmers cut the tree 30 cm above the ground (a process they call “zoca”)

Withdrawals from productive trees = Productive trees/Average time to cut tree

After the tree is cut, and until it grows back to the productive stage, they stay in the non productive trees stock.

Non productive trees = Integral (withdrawals from productive trees-Re-growing rate, non productive trees$_{t0}$)

A year later it becomes productive again and so the tree moves to a second age productive trees stock where the cycle repeats (trees grow, farmers cut and trees grow again). In Figure 26. we only showed this cycle once, but actually it happens 3 to 4 times. We left it out of the picture to make the explanation easier, but in the final model we modeled the complete life cycle of the trees.

Figure 27., shows a complete picture of the structure of the model, which includes both the supply side and demand side and now we have enough structure to reproduce the reference mode described in previous sections.

The rest of the equations can be seen on the appendix section

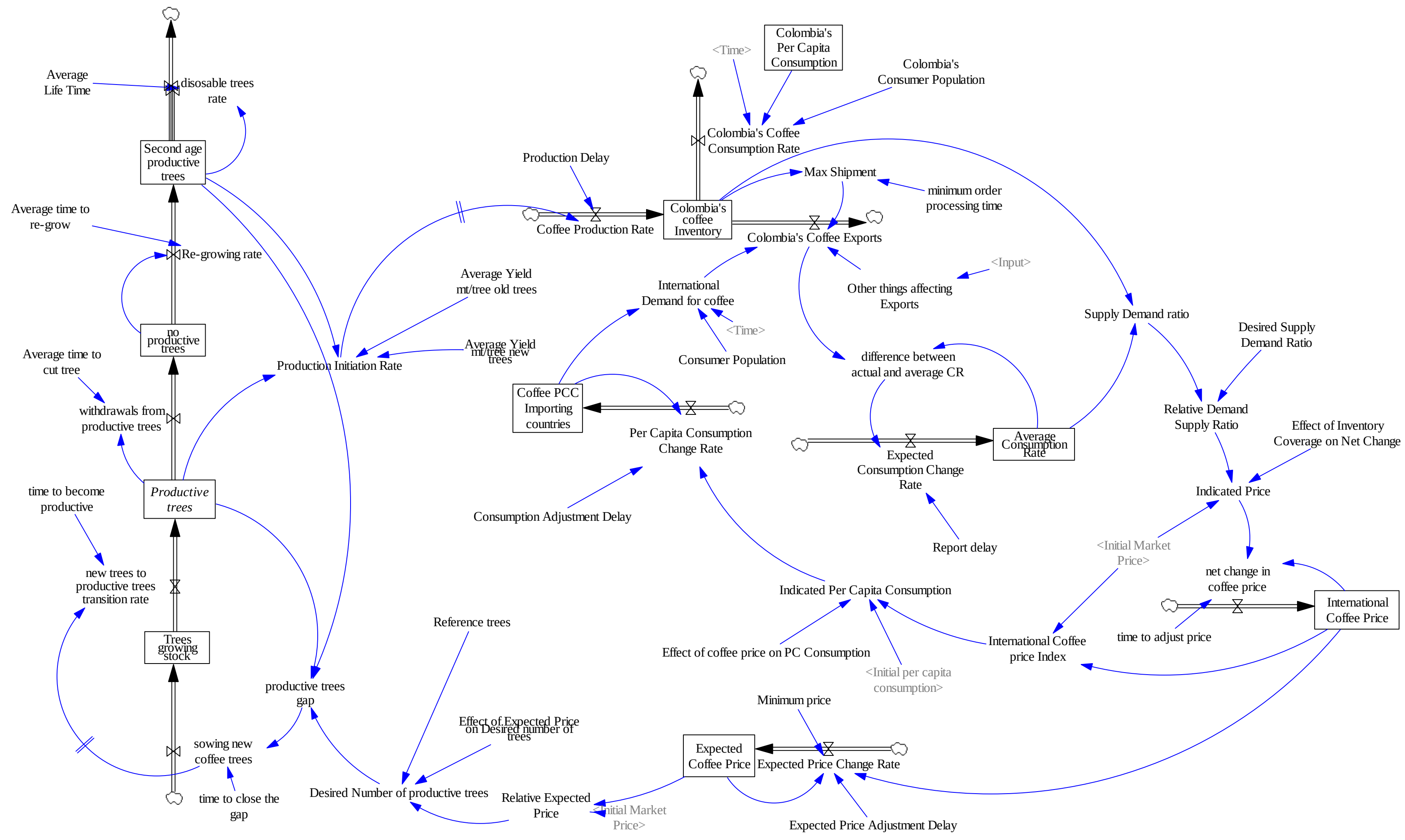

Figure 27. Full model stock & flow diagram

5 Model Testing

In this chapter we test our model by doing various tests. First, we run an equilibrium test. Then we run some structure tests. We follow checking whether our model replicates the reference mode or not. After that, we run the model under some extreme conditions to see if the model is robust under them. We end this chapter by doing some sensitivity tests to some of the most significant parameters.

5.1 Reference Mode Replication Test

In the following graph we compare the basic run of the Colombian coffee sector model with the reference mode described in chapter 3. The purpose of this test is to see how good our model replicates historical data. Figure 28. shows the simulated results for the international coffee price. We can conclude from the graph that our model produces a good replication of the historical data.

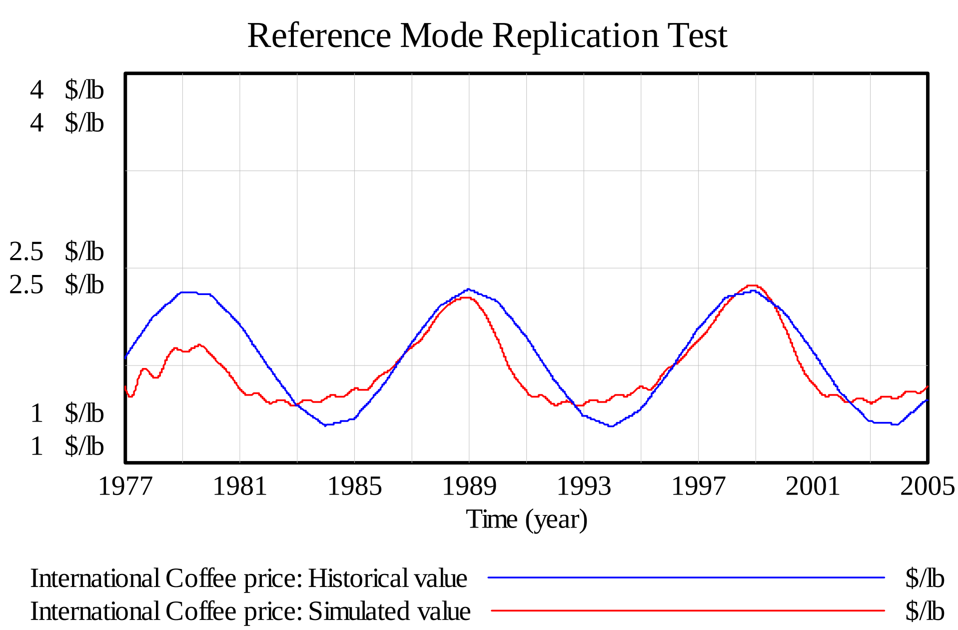

Figure 28. Reference mode replication test

5.2 Equilibrium Test

The equilibrium test will allow us to check if our model can be in equilibrium. It will also allow us to check if the oscillations could be originated endogenously.

The following figure shows the international coffee price when our model is in equilibrium.

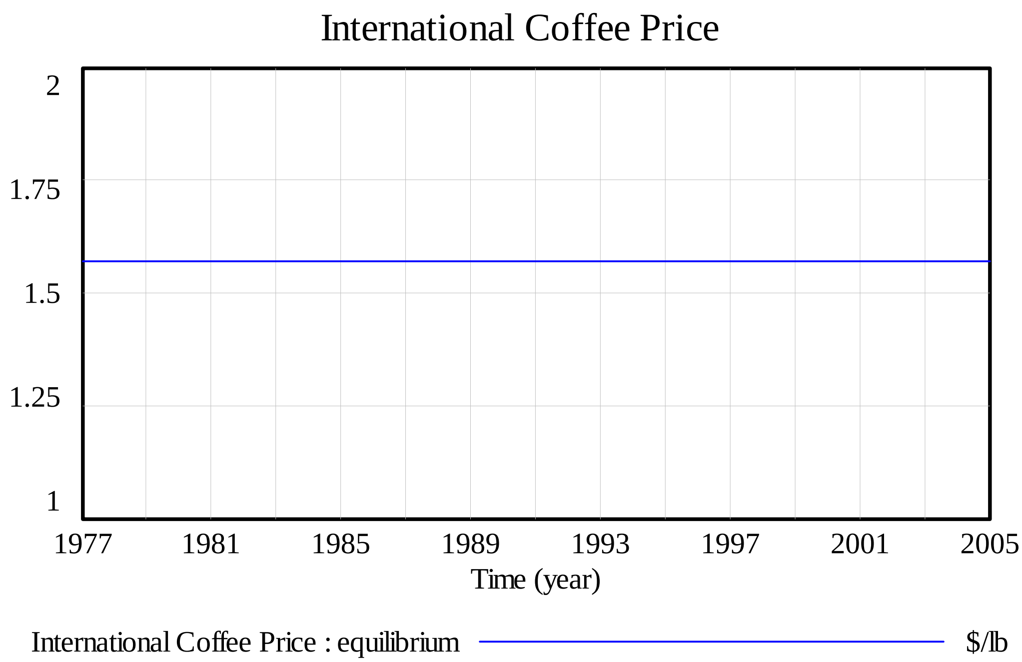

Figure 29. Equilibrium Test: International Coffee Price

Figure 30. shows the input we used to shock the system when it was in equilibrium.

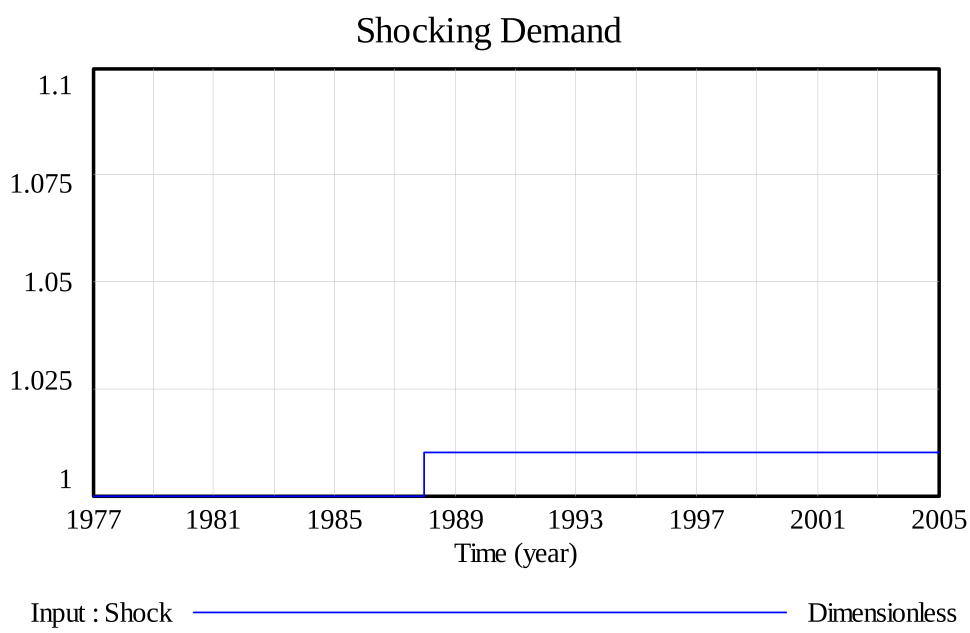

Figure 30. Demand Shock

We can infer from the previous figures that our model can be in equilibrium. Let's see what happens when we shock demand using a step function and increasing normal demand 10% at 1988. Figure 31. shows that the model produces oscillations again. This means that oscillations in this system can be originated endogenously.

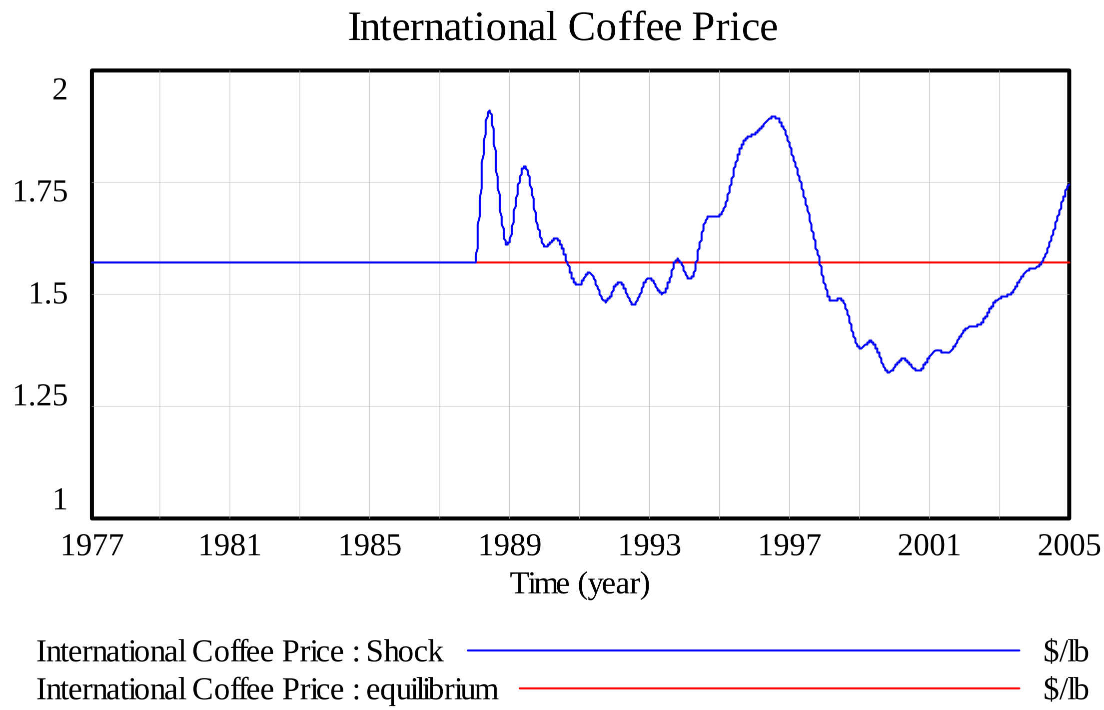

Figure 31. Equilibrium Test: International coffee price. Demand shock

5.3 Structure-behavior test

Our hypothesis was represented in CLD terms in Figure 12. We previously said that the interaction of those loops in Figure 12. and the long time delays involved in the system are the ones that might cause oscillations. In order to test this hypothesis we cut the balancing loop B2[14] and compared the behavior before (Figure 28., with the initial parameters) and after (changing some of the adjustment times). To cut this loop we make the production delay very big (1e+006). The following figures show that without the presence of the balancing loop B2 neither Colombia's coffee inventory nor International Coffee Price exhibit oscillatory patterns. This gives support to our hypothesis.

[14] We cut B2 for two reasons mainly: We consider this loop to have potential for policy implementations and second because our hypothesis considers the long time delays as the main reasons for oscillations in this system and loop B2 contains the longest time delay in the system: Capacity construction.
To see the results of the model after cutting other loops see Appendix 3

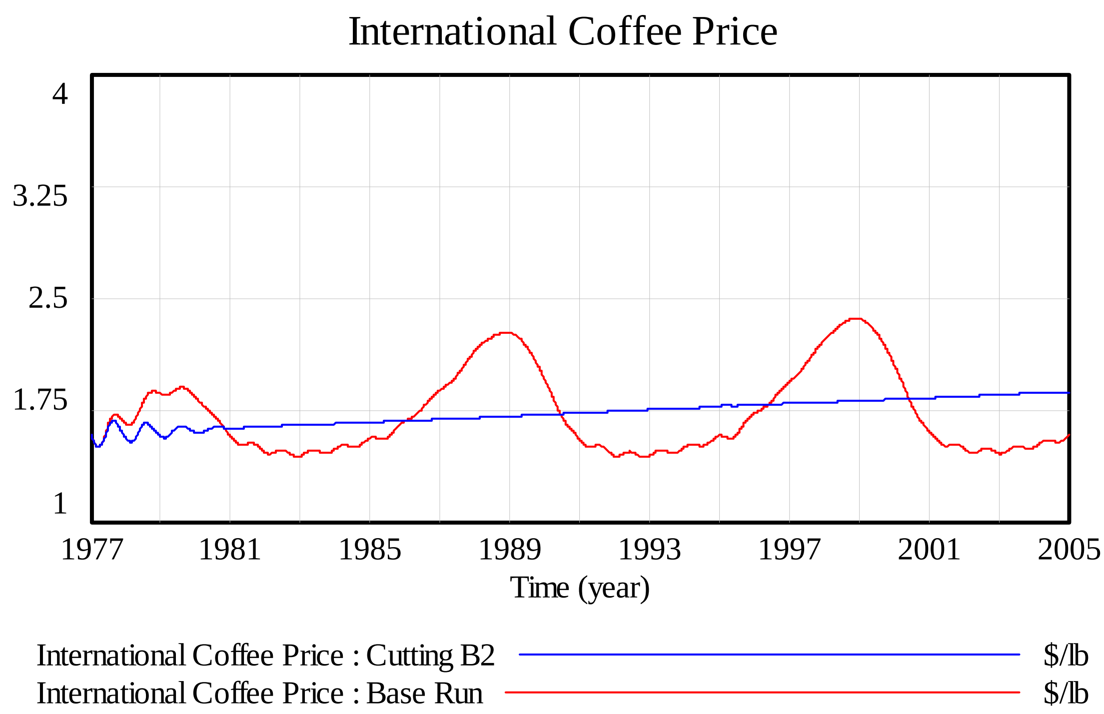

Figure 32. Behavior test: International coffee price, cutting loop B2

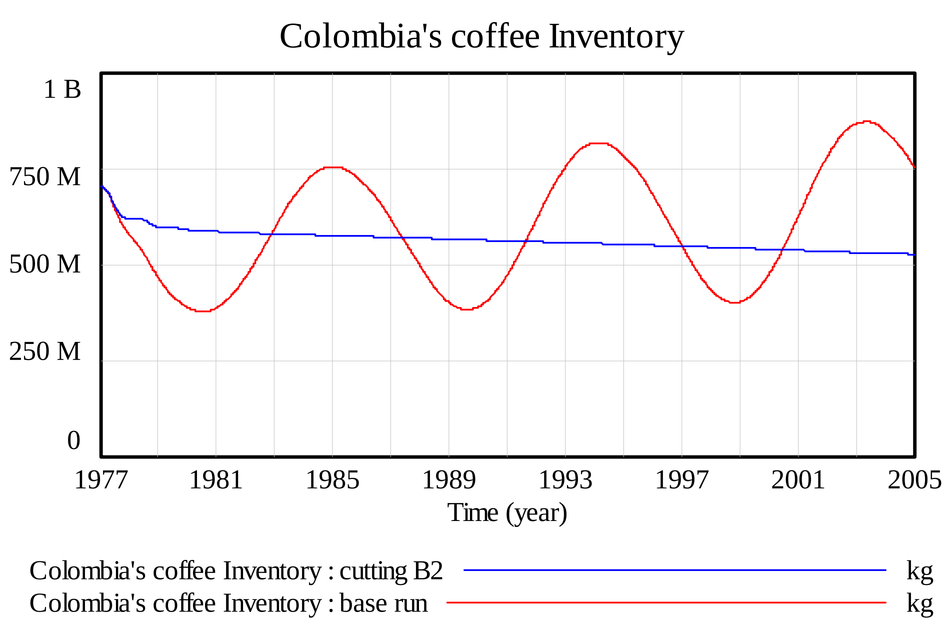

Figure 33. Behavior test: Colombia’s coffee Inventory, cutting loop B2

In the following figure we combined the structure test and the equilibrium test. Basically we started our model in equilibrium and then shocked it with the same input we used in section 5.1. The result: the coffee price tries to oscillate for a few moments but then it goes back to equilibrium. It clearly differs from Figure 31. Because after the shock, coffee price does not oscillate as it does in that figure. The structure-behavior test gives some support to our hypothesis and shows how the structure we formulated can create oscillations endogenously and also shows that oscillations can be dampened.

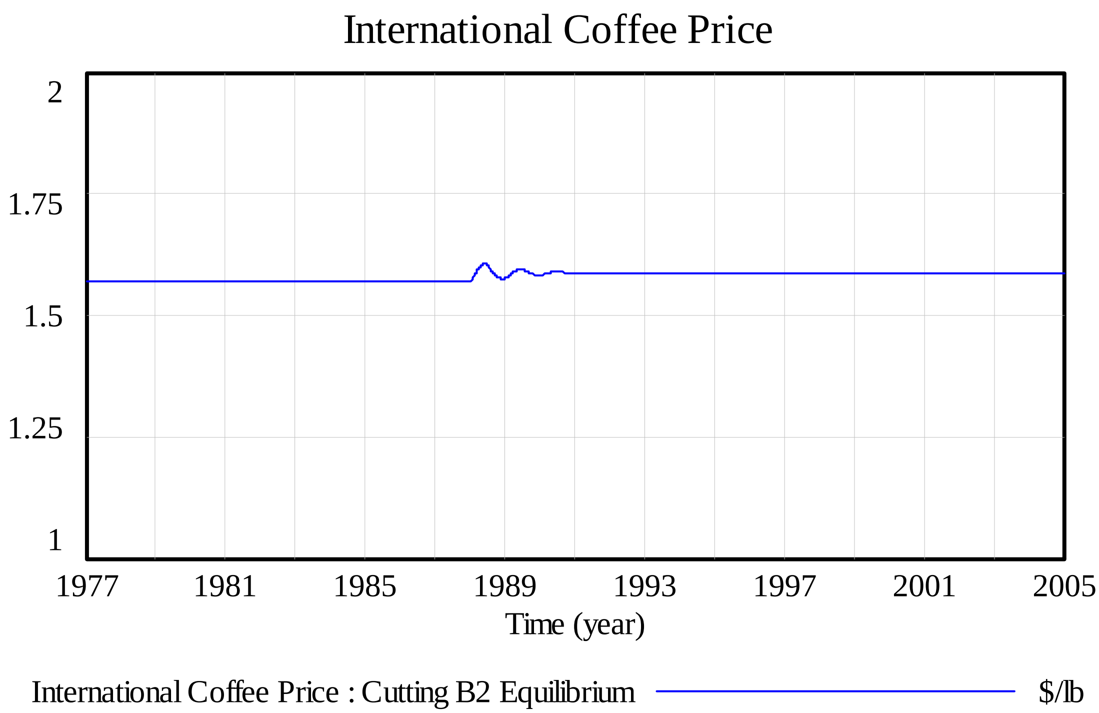

Figure 34. Behavior test: Colombia's coffee Inventory, cutting loop B2 and model initialized in equilibrium

5.4 Other tests summary

We ran few more tests to our model. We describe the results of those tests in this section to see more details refer to the appendix.

We conducted two extreme condition tests: One with no consumer population and a second one with productive trees and trees growing stock equal to zero. On the first test the result was the expected. With no people consuming coffee, *international coffee price* dropped. It dropped because no one was consuming coffee but since the minimum price policy was in place coffee growers maintain their coffee production. The second test did not produce the result we were expecting at first. With productive trees equal zero, production of coffee was zero as well. But there was still demand for coffee. This situation was depleting the inventories of coffee causing an increase of price. Even though price made it very attractive for the growers to invest in the sector, by planting new coffee trees they did not do it at productive trees remained zero during the entire simulation. The problem was the way we modeled the desired number of productive trees. Initially we used as the reference number of trees the sum of productive trees and since productive trees were initially zero they remain like that. To correct this issue we changed the reference trees for a constant value, an average value of productive trees. Then we ran the test again and got the expected results. The reduction of coffee production cause an increase in *international coffee price* and this cause an increase on the expected coffee price and this triggers the sowing of coffee trees.

We also run sensitivity tests to check how sensitivity our model is to changes in the value of some parameters, specifically those we have the least confidence in. Table 2. Shows the list of parameters we changed and the minimum and maximum values we used to run the test. We have confidence in the last 7 parameters in table 2. So we did sensitivity test with the first 6 parameters.

List of parameters:

Parameter	**Original Value**	**minimum value**	**maximum value**
Consumption Adjustment Delay	0.3	0.2	0.8
Report Delay	0.1	0.02	0.18
Time to adjust price	0.25	0.1	1
Expected price adjustment delay	0.1	0.02	0.3
Time to close the gap	0.5	0.3	0.7
Desired supply demand ratio	0.8	0.5	1
Minimum price	1.5		
Time to become productive	2		
Average time to cut tree	4		
Average time to re-grow	0.5		

Average Life Time	3	
Average Yield	0.25	
Production delay	0.2	

Table 2.Model Boundary Chart

We analyzed with the sensitivity test if our model was numerically and behaviorally robust. When we varied one parameter at a time the model was robust in both aspects. In all of the tests the behavior remained the same. Numerically, we can say that our model is not very sensitive, it does have changes but they are not significantly high.

In this chapter we ran and showed the results of some test in order to help the reader to build confidence in our model. Among those tests were the equilibrium test, structure- behavior test and the replication test. Besides those tests we also conducted, the extreme condition test and the sensitivity test. Finally we also checked units and errors with Vensim finding no errors and perfect unit consistency in the model.

6 Policy Design

In this section we add new structure to our model to evaluate policy options for dampening the oscillations. Specifically we build structure so the decision of building new capacity considers also the capacity production that is in progress. We also test the impact of the minimum price policy.

6.1 Managing capacity

Every time the coffee price changes, the coffee farmers expectations also change. Farmers then want to either invest more (if price increases) or less (if price decreases) but too often the time it takes to plant new trees and have new productive trees or change crops is not taken into account. Basically, we assume coffee growers do not perceive the trees growing stock because these trees are not productive and coffee growers based their decisions on the amount of coffee harvested. Therefore we propose to add structure to count the trees that are growing but are not productive yet. So instead of comparing growing trees only with actual number of productive trees, farmers will also consider the non productive trees. The following figures show CLD and SF diagrams including the capacity under construction (the new structure is in red color in both figures). Basically we add another counteracting loop (B5) to control the decision rule of the coffee growers to sow new trees. With this new structure we are managing the stock of growing trees. We compare the desired number of no productive trees with the actual number of trees (no productive trees) creating the gap of no productive trees.

Non productive trees gap = Desired number of non productive trees-(Trees growing stock + no productive trees)

We assumed both “Non productive trees gap” and “productive trees gap” need the same time to be adjusted and we add both to form the amount of desired productive trees.

Desired Productive trees = productive trees gap + Non productive trees gap

Figure 37. and Figure 38. show the behavior of international coffee price and productive trees after adding the structure to our model in order to take into consideration the capacity that is

under construction. They show how productive trees become more stable making production of coffee stable as well. Therefore, and because coffee consumption is more stable, international coffee price oscillations are dampened and it almost stabilizes around $2.2 per pound.

Implementing this policy in real life could be done by inventorying coffee trees (conducting a census of trees every year or every two years for instance) and controlling the number of trees planted, or a more extreme situation, by controlling the distribution of new seeds (for example selling certified seeds and the distributor of these seeds should be only the federation). While doing this research we found that there is little control on these issues. Our hypothesis is that coffee growers misperceive the delays involved in the capacity construction. They oversee the number of coffee trees that are growing. They only perceive the harvest (kg of coffee per season) so when they decide to plant new seeds they don't wait long enough to see the results, overbuilding capacity for instance.

What we intend with this policy is to manage the inventory under construction and avoid the excess or shortfall of production. We considered the following steps and the responsible to implement this policy:

1. Education plan for the coffee growers (responsible: FNC). It is of great importance to explain to coffee growers the consequences of overbuilding capacity and its implications in price and therefore in their income[15]. The same media used nowadays to communicate with the coffee growers should be used to spread the education plan.
2. Both FNC and coffee growers should be aware all the time of the number of productive trees. Therefore we propose that a census of trees is conducted periodically (responsible: FNC)
3. Development of an incentives and fines plan for those growers that exceed the amount of coffee trees "allowed" (should be settled in consensus by FNC, government and growers).

[15] During this research we assumed how coffee growers are deciding the number of productive trees. In order to create an appropriate training plan, more research should be done in this aspect to validate our assumption.

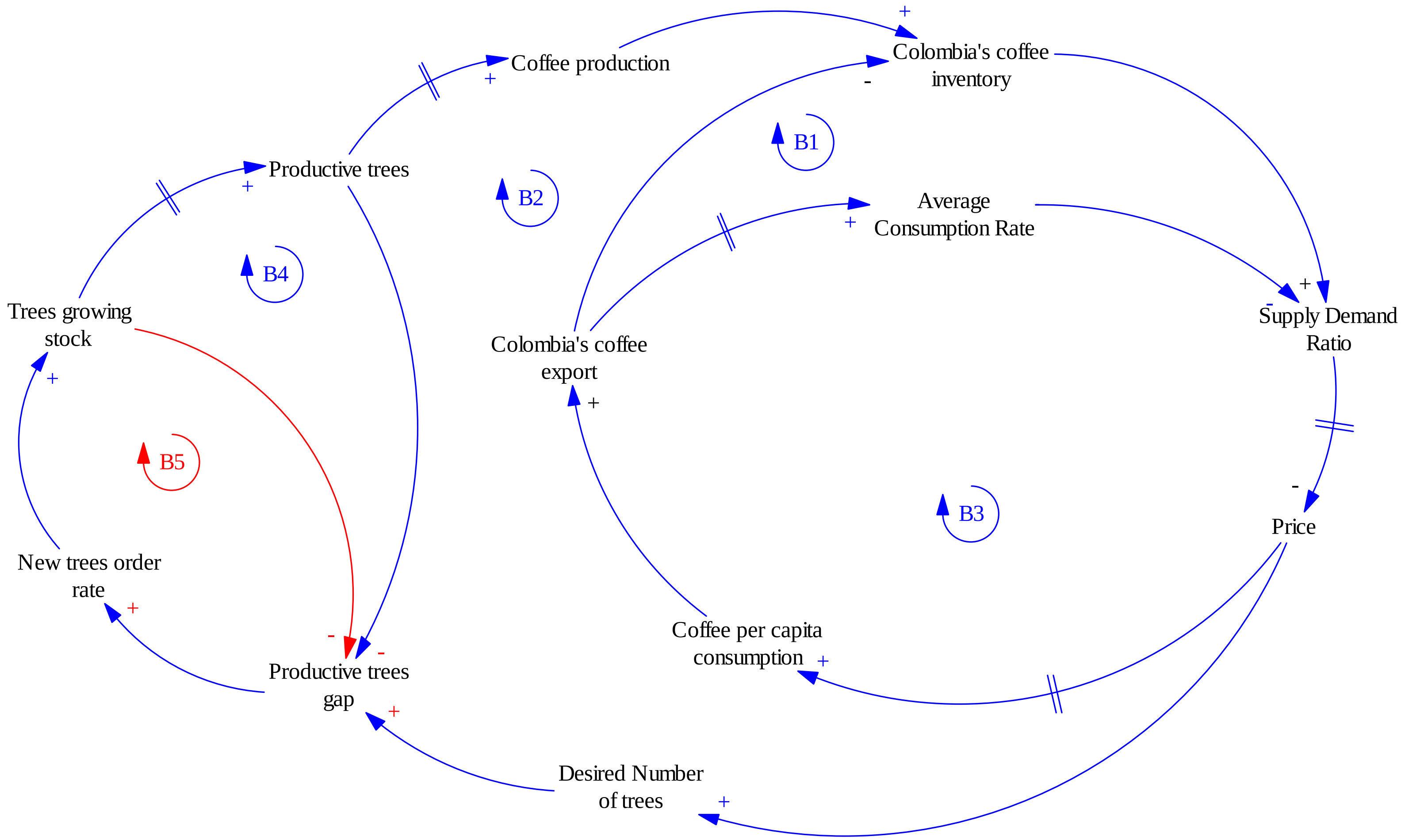

Figure 35. Considering capacity under construction policy (CLD).

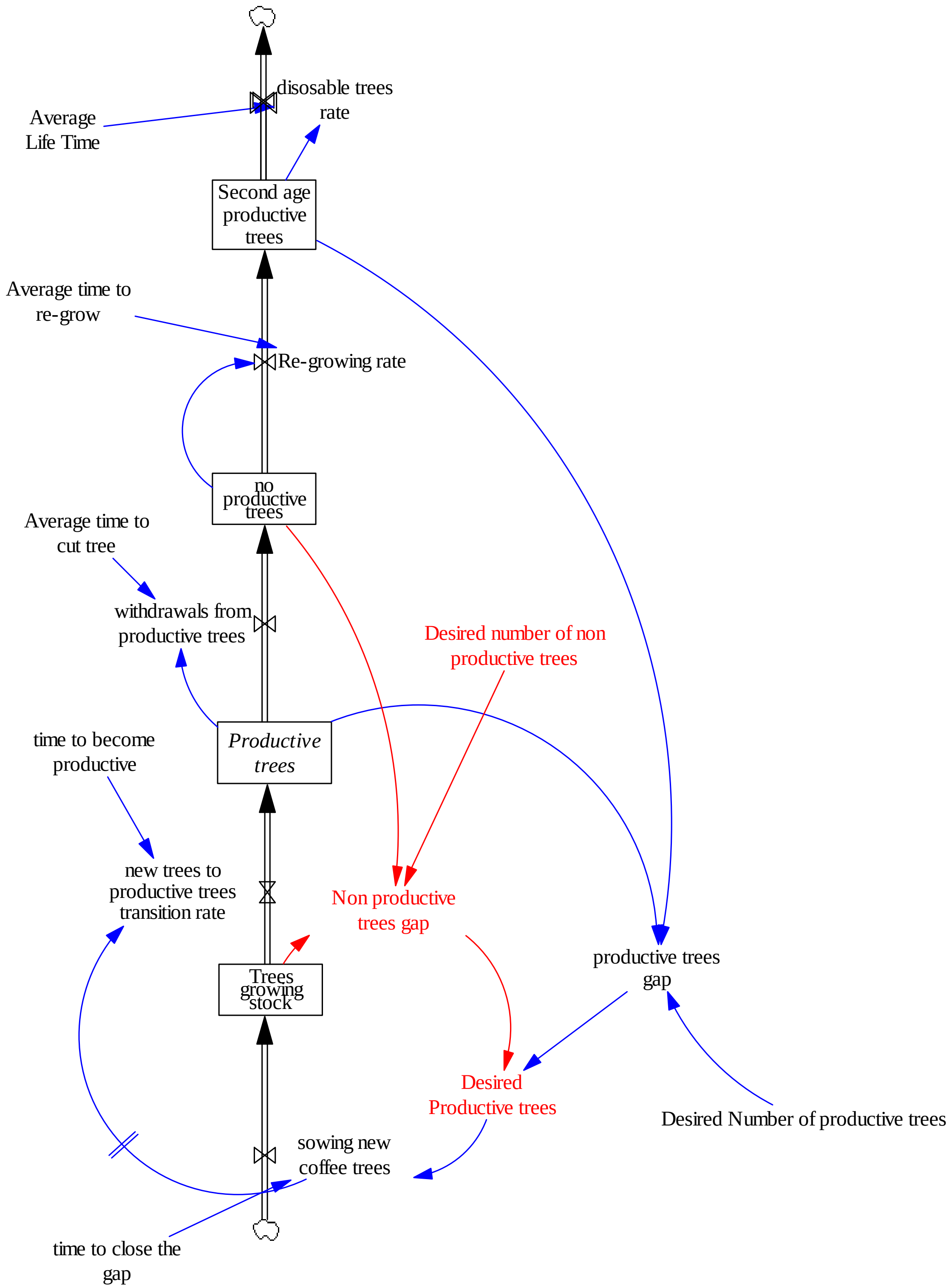

Figure 36. Considering capacity under construction policy (SFD).

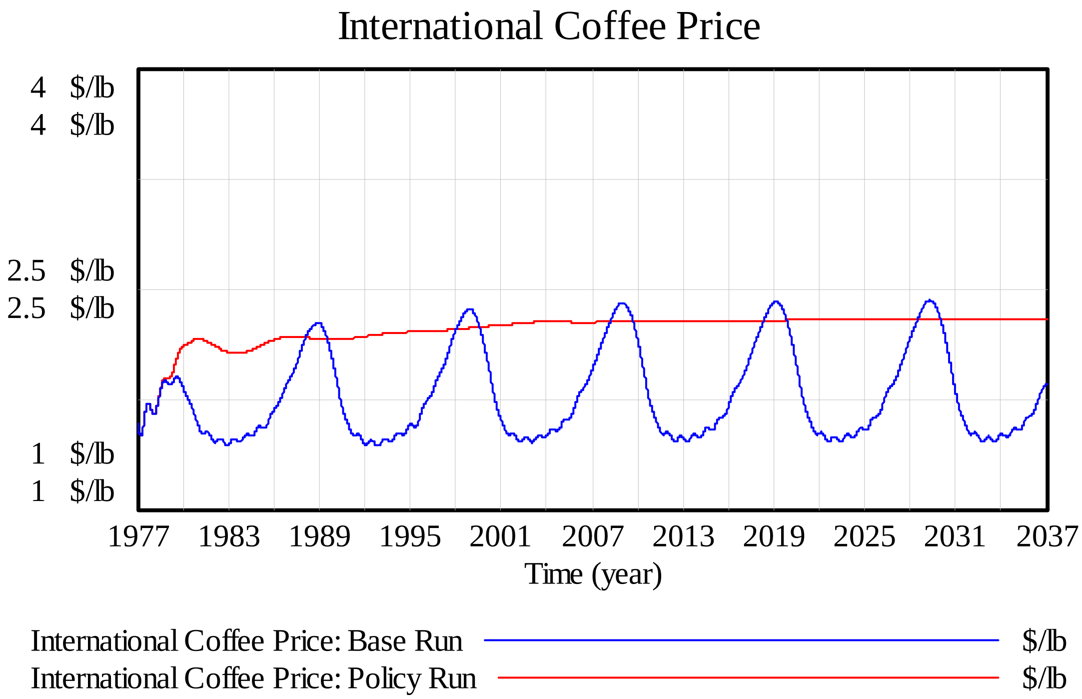

Figure 37. International coffee price considering capacity under construction policy.

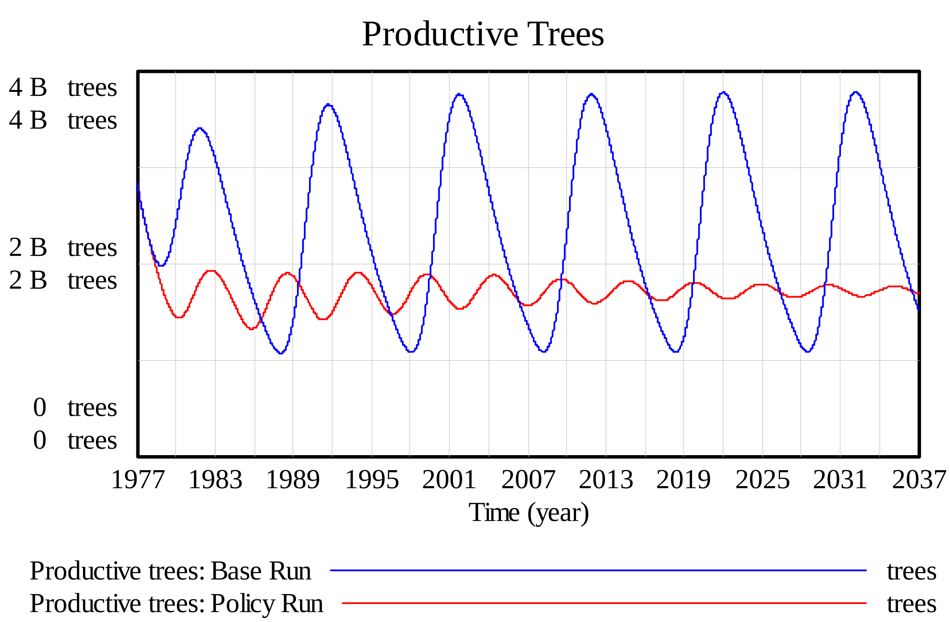

Figure 38. Productive trees considering capacity under construction policy.

In this case we assumed the policy was 100% effective and goes into effect immediately after adoption. Therefore we are going to run few more scenarios. First, assuming our policy is only 50% effective and second assuming a time delay in our policy (time it takes to conduct a census and receive the results). In the first case we assumed only 50% of the growers will take into account the capacity under construction, therefore we multiplied the number of productive trees by 50% assuming that only 50% will be taken into account. The other 50% will still misperceive the capacity under construction and will not consider those trees that are not productive.

Non productive trees gap = (Desired number of non productive trees-(Trees growing stock + no productive trees))*Policy effectiveness)

In the second we assume that there is a one year delay to report the actual number of non productive trees, in this case the equation of the gap is

Non productive trees gap = (Desired number of non productive trees-delay1 ((Trees growing stock + no productive trees), 1))

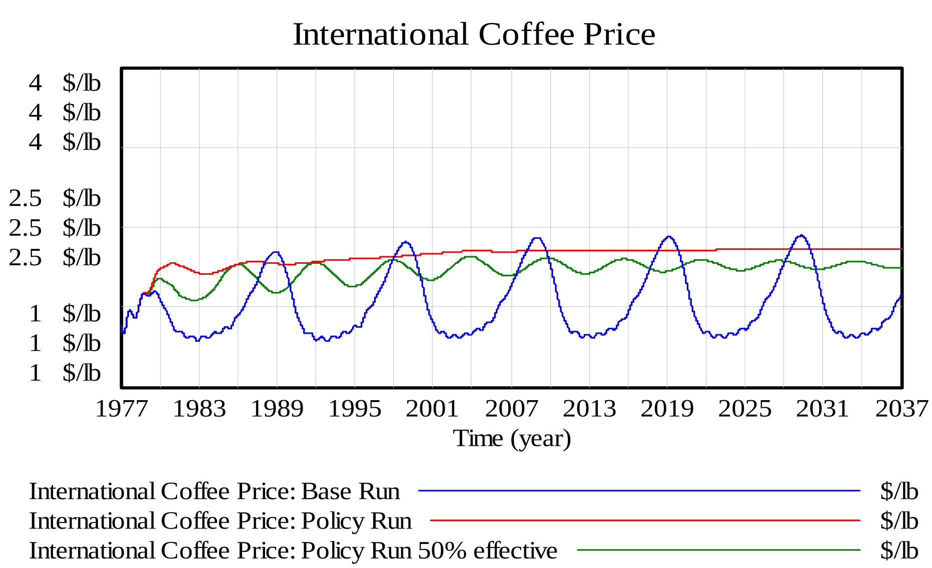

Figure 39. International Coffee Price considering capacity under construction policy 50% effective.

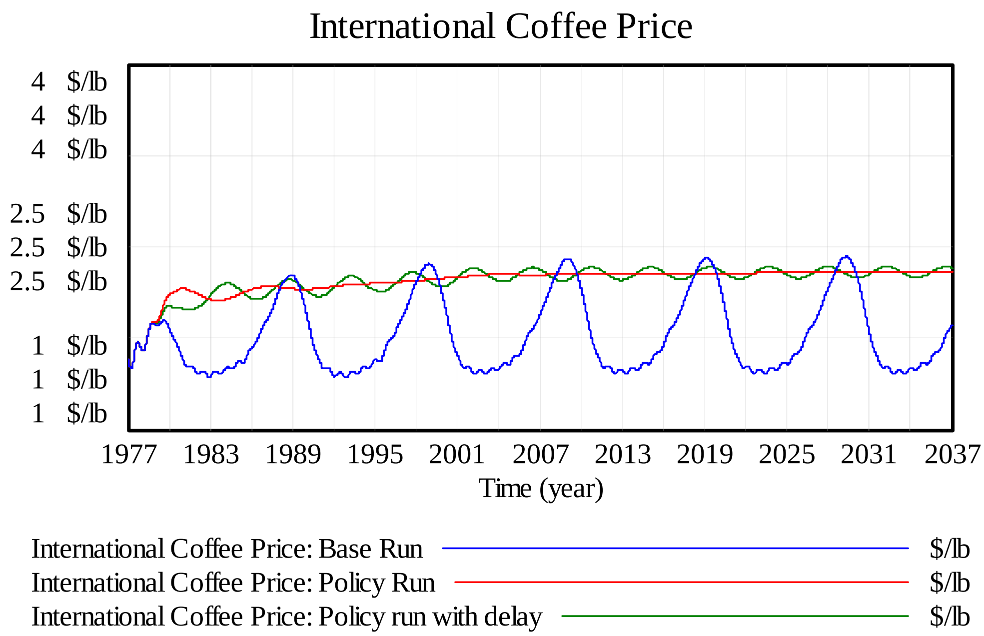

Figure 40. International Coffee Price considering capacity under construction policy including delay.

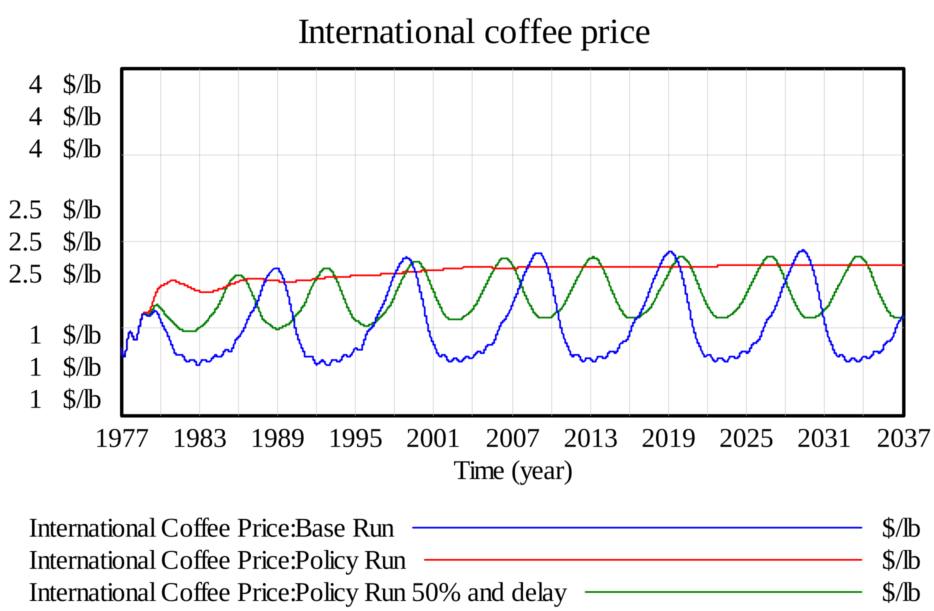

Figure 41. International Coffee Price considering capacity under construction policy including delay and 50% effective.

Figure 39. shows how even if only the 50% of the growers take into consideration the capacity under construction or only 50% of them are controlled by the federation on the number of coffee trees they have, the policy will still be effective and will diminish the oscillations. Figure 40. shows the result of the policy when we added a delay when closing the gap between trees growing stock and desired productive trees (*Non productive trees gap)*.Finally, Figure 41. Presents the result under both conditions (50% effective and a delay). Although the result is not as good as in Figure 39., oscillations are dampened as well.

6.2 Minimum price

Now we are going to focus on simulating the impact of the minimum price policy. The minimum price parameter is used by the FNC[16] to try to provide a stable income to the coffee growers. The Federation intends with this two things mainly: help growers in rough times and dampen or reduce volatility. Therefore we ran a sensitivity test to check how this parameter affects the results of the model. Figure 42. shows the result of the test when we varied minimum price randomly with an uniform distribution within 1 and 3 ($/lb). It shows that our model is numerically sensitive but not behaviorally sensitive to changes in this parameter. Let's analyze this parameter to see the effects on the Colombian coffee price and to do so we run two more scenarios: 1) Minimum price below the base run level ($1/lb) 2) Minimum price above the original value (<$2/lb)

[16] FNC sets the minimum price based on the International Coffee Price, a quality bonus paid to Colombian coffees and the exchange rate (COP vs US dollars)

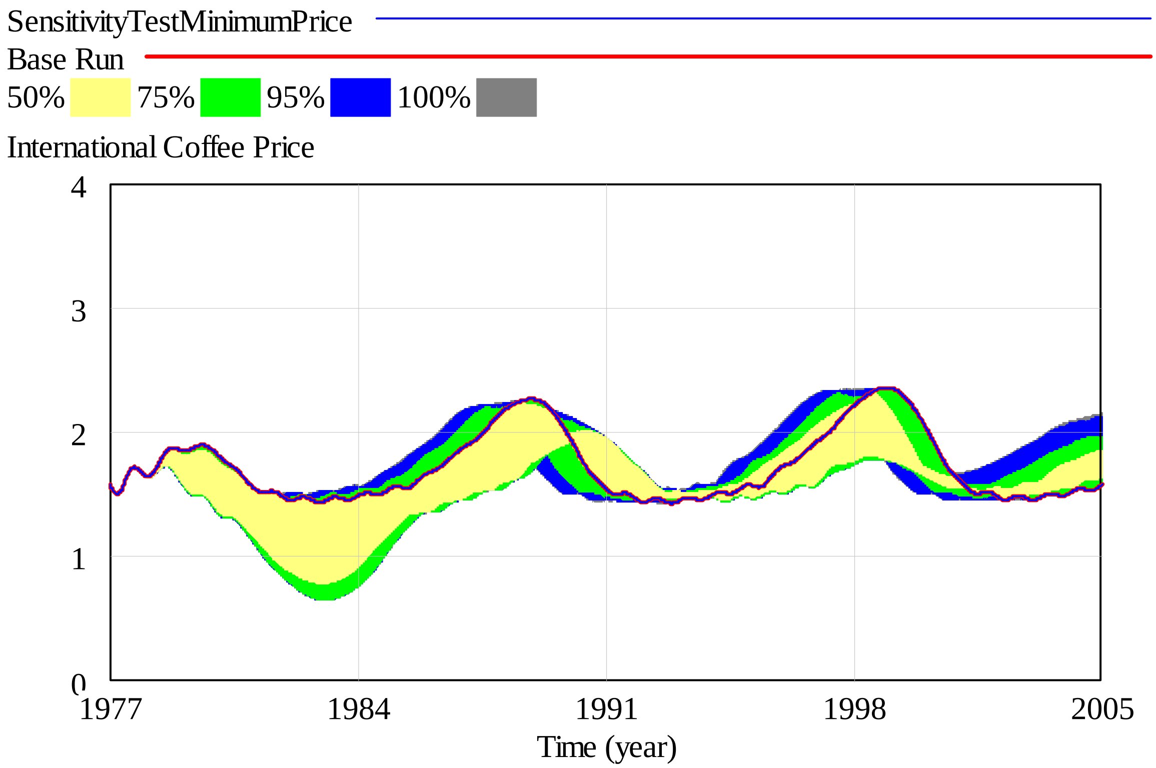

Figure 42. Parameter sensitivity test: International coffee price when Minimum Price varies within 1 and 3 $/lb

On the first scenario (Figure 43.) the situation does not change mainly because coffee price is always above the minimum price and therefore this policy does not apply, e.g., coffee growers always get the international coffee price.

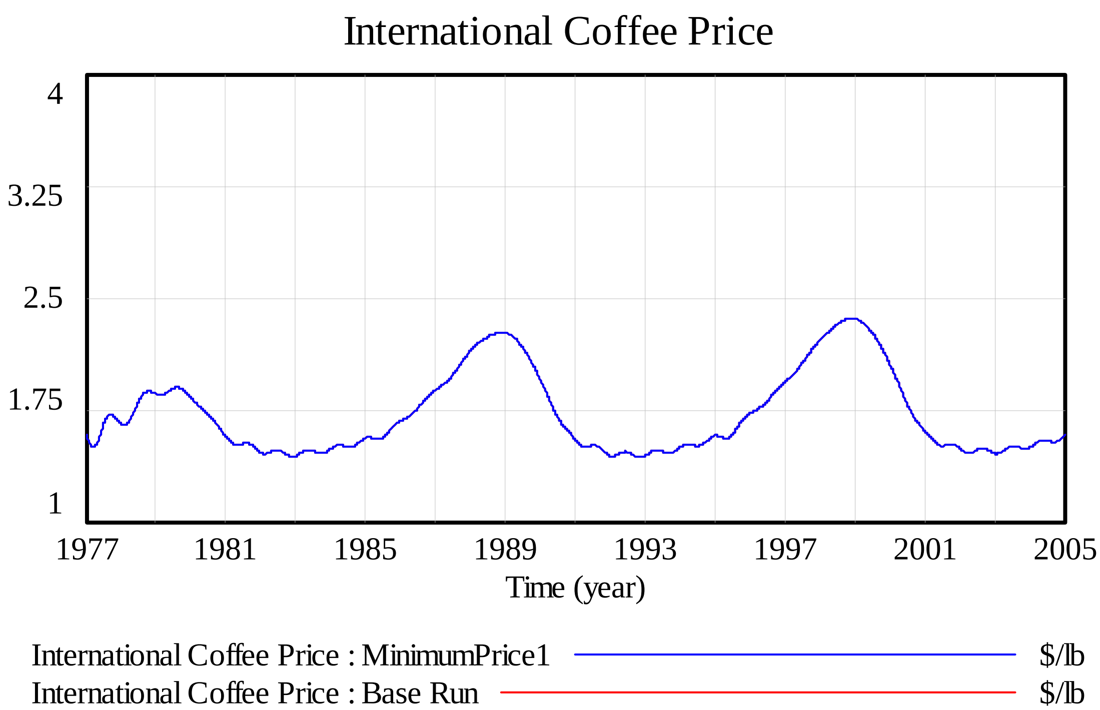

Figure 43. International coffee price when Minimum Price = 1

Figure 44. shows the results when minimum price is set to $2/lb. In this case the minimum price policy reduces the amplitude of the cycle, though the cycles remain. This policy is not profitable for the Colombian coffee federation because, as we previously said, international coffee price is always lower than the minimum price.

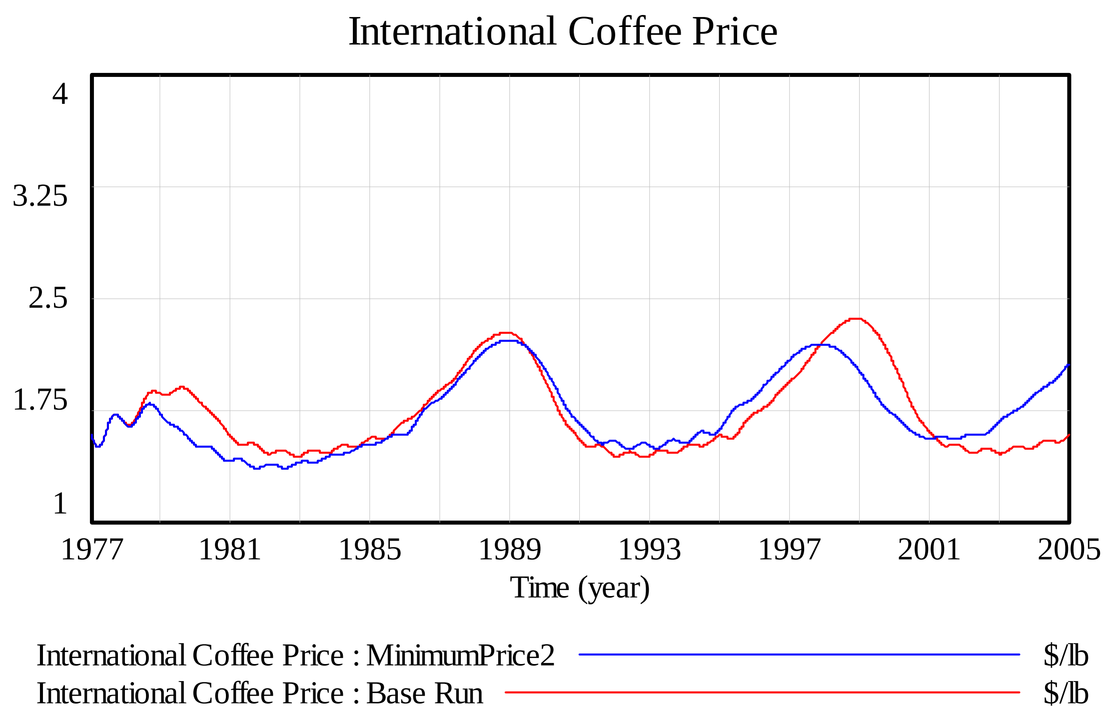

Figure 44. International coffee price when Minimum Price = 2

We can argue here that the minimum price policy does not significantly reduce the cycles but it does help coffee growers reducing the risk. Coffee growers buy some sort of insurance and when international coffee price is below the "Sustainable Price"[17], FNC will pay the grower the minimum price then.[18]

[17] Sustainable price is equal to the average cost of producing a load of coffee in Colombia.
[18] For more technical information on the minimum price policy visit www.cafecolombia.com/docs/presentacion.pdf

7 Conclusion

We have shown in this paper that the Colombian Coffee market structure we proposed can produce oscillations endogenously. To prove this we started our model in equilibrium and by shocking the system with a very simple input (step function increasing 1% demand) we got oscillations again. We also show how by learning about the delays involved in this system and managing them, its behavior could be improved, reducing oscillations and at the same time improving conditions for coffee growers.

If there is some control to the actual capacity, to the capacity under construction and either FNC or coffee growers create mechanisms to recognize the time it takes for the coffee trees to become productive, oscillations can be dampened; at least the oscillations that can be generated endogenously. We propose for instance to conduct a census of the productive trees and the trees growing stock every year. Another option is to control the trading of seeds.

We run tests to see the impact of the actual policy of FNC, Minimum price policy, and saw that this policy is not dampening the oscillations. Perhaps it helps coffee growers to have a more steady income but we do not see a big impact reducing oscillations.

We also identified future work or research that could arise from our work. The boundaries of this research do not include important variables like Robusta coffees. We did not consider inventories of other types of coffees and their impact on the price of Mild Arabicas. Future works could include also these actors.

In this paper we assumed how coffee growers take their decisions. It would be interesting to test in a controlled experiment how coffee growers really decided about their desired number of trees. This will give a more accurate insight of the problem and confirm whether the problem of oscillations is caused because coffee growers misperceive the long time delays involved when they decide on the desired number of productive trees.

This model could be used as point of departure to introduce other actors (like other producer countries) and other types of coffee and run similar test to the ones we ran here. For example it would be interesting to test a policy like the FNC minimum price policy.

This model could also serve to model the impact of International Coffee Agreements on coffee price.

Our model was not intended to make predictions but it will be interesting to include a trend function for price this will allow to forecast price and establish some short term policies.

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Internet Resources:

www.ico.org

http://www.mde.edu.vn/thuduyen.asp

http://www.cafedecolombia.com

http://www.american.edu/ted/coffecolombia.htm

http://www.worldbank.org/

http://www.dane.gov.co/

Appendixes

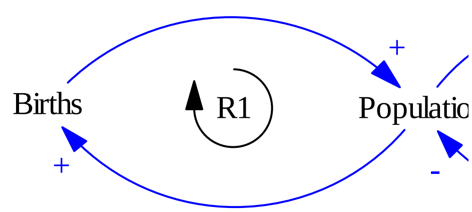
Appendix 1 System Dynamics concepts

System Dynamics (SD) is a methodology to study complex systems by analyzing the interaction of the variables and actors involved in the system. System dynamics considers that the behavior of a system is caused by the structure of the system, e.g., the delays, the stocks, flows and feedback in that system. The main concepts of system dynamics are: Stock, Flow and Feedback.

Stock refers to accumulation. The stocks are the indicators of the system. The stocks inform the state of the system and normally decision makers take decisions based on the level of the stocks.

Flow is the medium how a stock changes. We manage stocks through their flows. In a mathematic way stocks are integrals and flows are derivates.

Feedback is how the actors in the system interact. Assume A is a flow and B is stock. A variable “A” affects a variable “B”, this means “A” affects the state of the system, “B”. But again “B” affects the variable “A”. Let’s see this with a graphical example, in the next figure Births represents the variable we called “A” and Population would be variable “B”. The more births the more population and to complete the loop, the more population the more births.



REFERENCE MODE

System dynamics models should focus on a specific problem of a system, study the problem and help people to find and understand causes and evaluate possible solutions for the specific problem. In order to correctly address a problem one should clearly identify how the problem looks like, in other words, a problem should have a clear reference mode. Too often historical data includes “noise” and other data a modeler is not interested on study or replicate. As Saeed (1998) says, modelers tend to interpret the historical data as their reference mode.

Saeed (1998) suggests one should separate the “multiple modes” present in the historical data to isolate a problem and create a model that is more appropriate to see the impact of specific policies. Figure 45. extracted from Saeed’s paper shows two examples of composed and decomposed data sets.

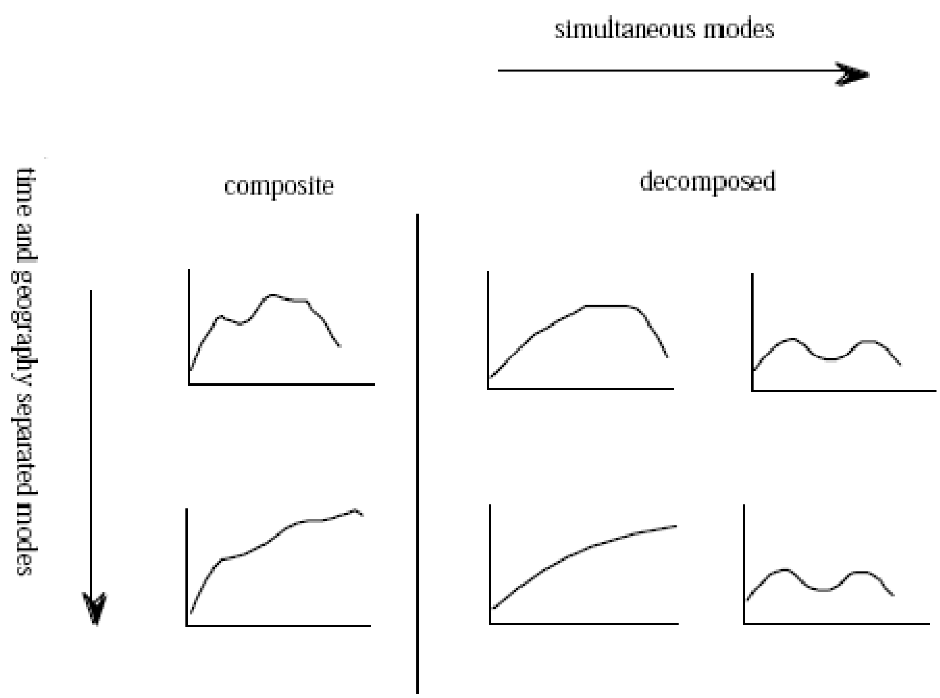


Figure 45.decomposing historical data

Source: Saeed, 1998

Appendix 2 Model testing results

Sensitivity Test

We run some sensitivity tests, to check how sensitive our model is to changes in parameters the values of which we have the least confidence. First we run those tests changing one parameter at a time and then we run a multivariate test (we change all parameters at the same time)

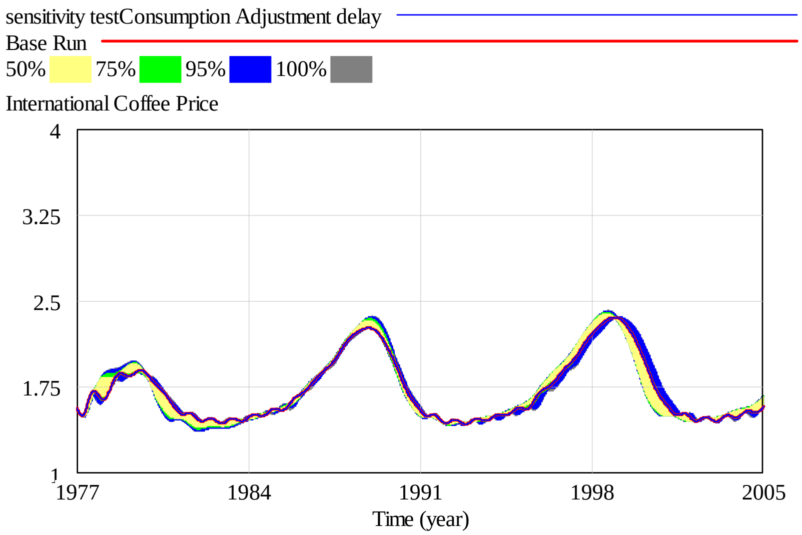


Figure 46. Parameter sensitivity test: International coffee price Consumption adjustment delay = 0.2 to 0.8

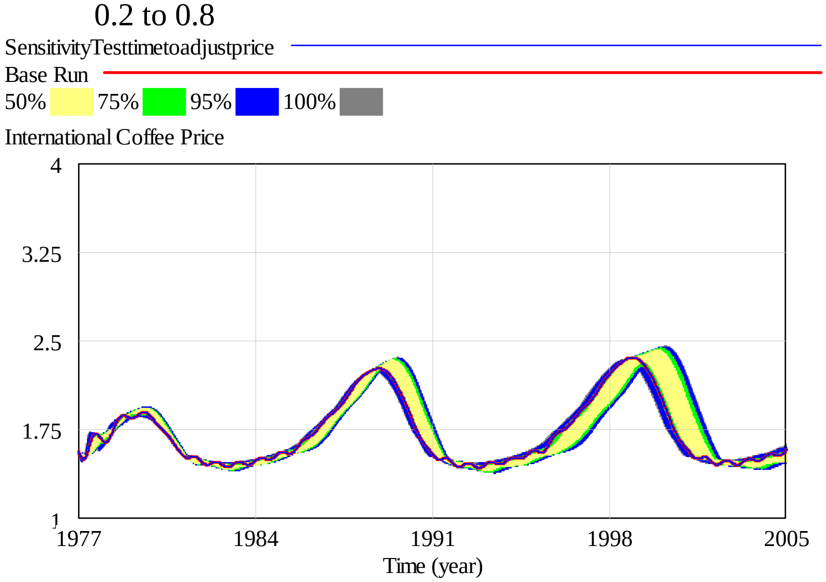


Figure 47. Parameter sensitivity test: International coffee price Time to adjust price = 0.1 to 1

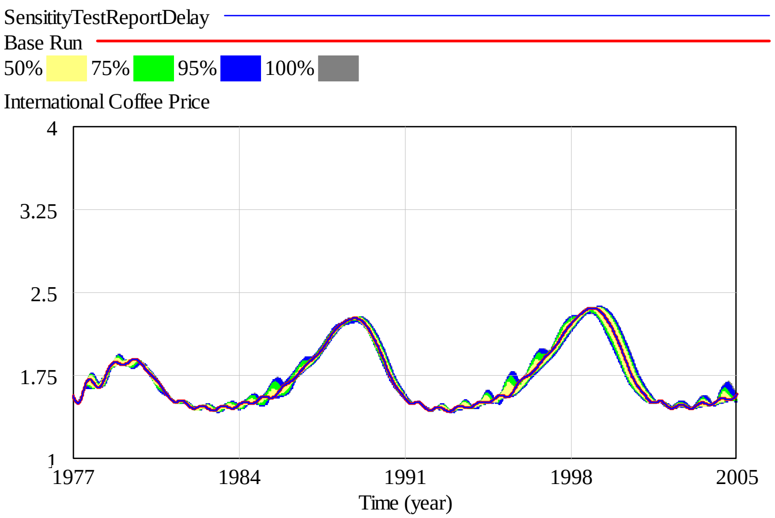


Figure 48. Parameter sensitivity test: International coffee price

Report delay = 0.02 to 0.18

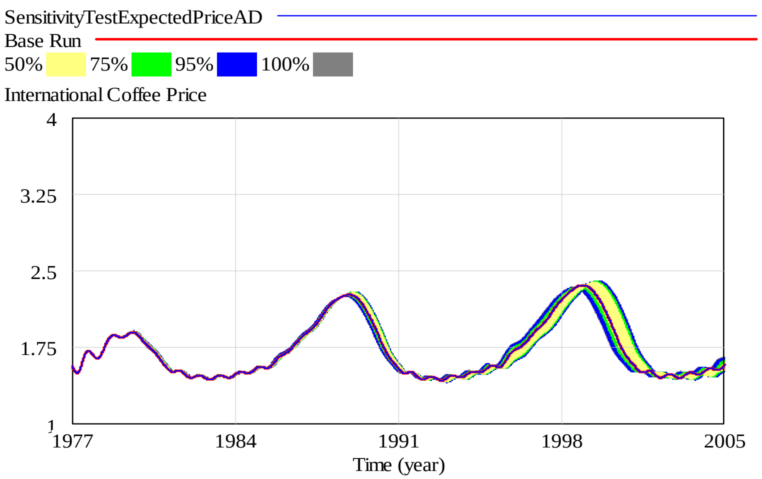


Figure 49. Parameter sensitivity test: International coffee price

Expected Price AD = 0.02 to 0.3

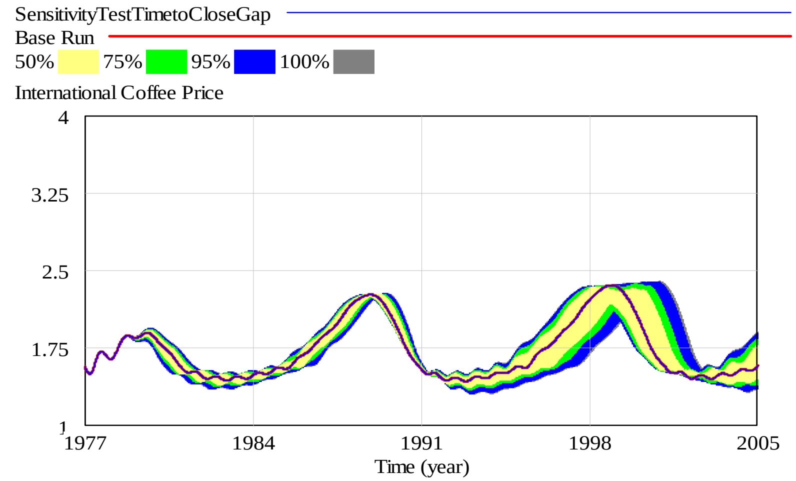


Figure 50. Parameter sensitivity test: International coffee price

Time to Close gap = 0.3 to 0.7

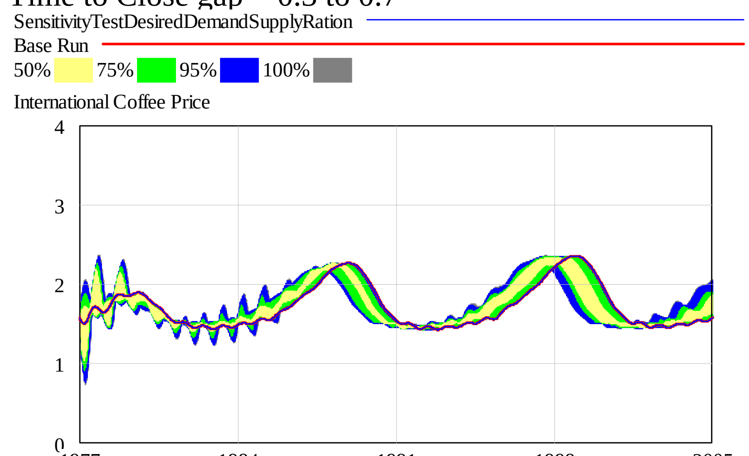


Figure 51. Parameter sensitivity test: International coffee price

Desired Supply demand Ratio = 0.5 to 0.1

Figure 46. to Figure 51. show the results of the sensitivity tests when we changed one variable at a time. The graphs show that our model, behavioral wise, is robust. That means the behavior mode did not change fundamentally when we vary the parameters in Table 2. We can also say that the model is not very numerical sensitive either. The numerical results of the model only varied significantly when we changed the Time to close the gap parameter (Figure 50.)

Figure 52. shows the results of the multivariate sensitivity test. It shows that the model produces the same pattern (oscillations) even when we made all the parameters we are no completely sure about to change at the same time. The results of the model do change numerically but our model itself is not intended to forecast Colombian price. The most important fact is that the model keeps producing the same pattern of behavior.

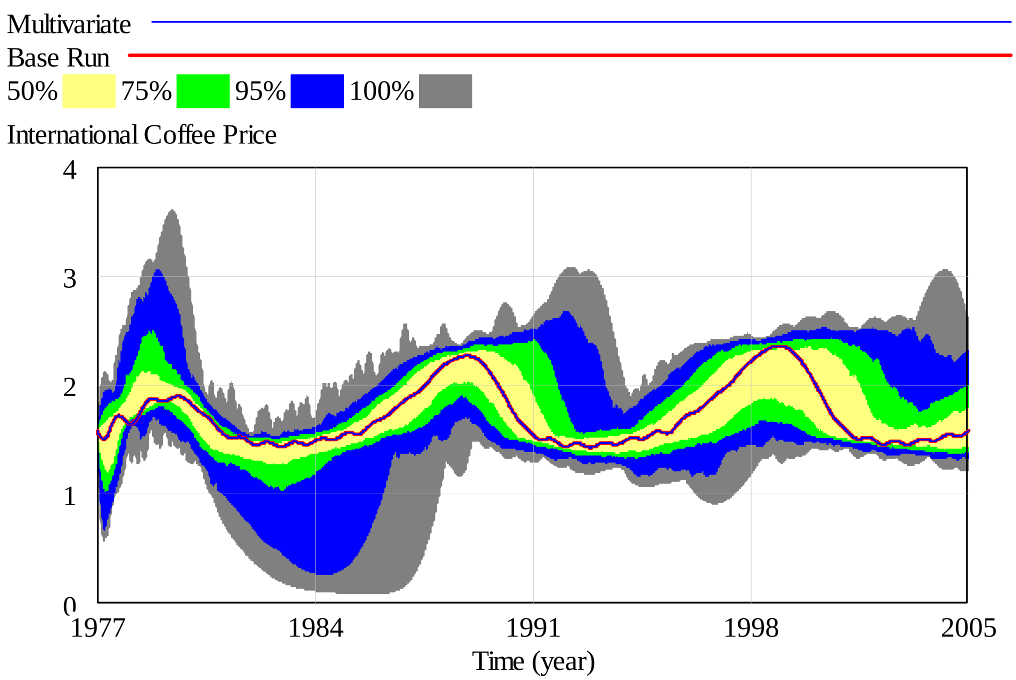


Figure 52. Parameter sensitivity test: International coffee price Multivariate

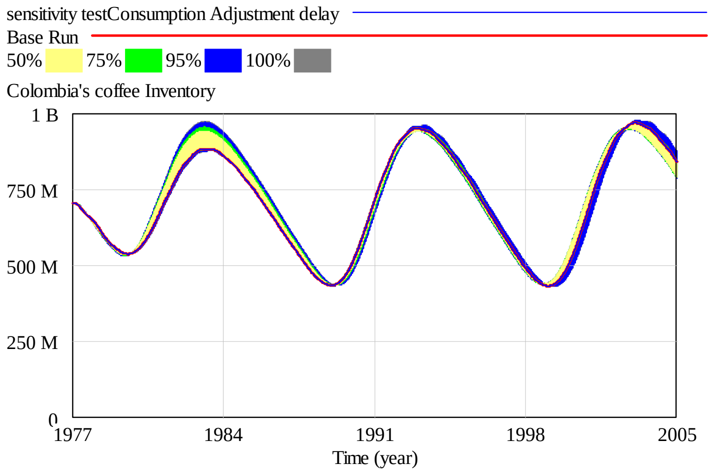


Figure 53. Parameter sensitivity test: Colombia’s coffee inventory. Consumption adjustment delay = 0.2 to 0.8

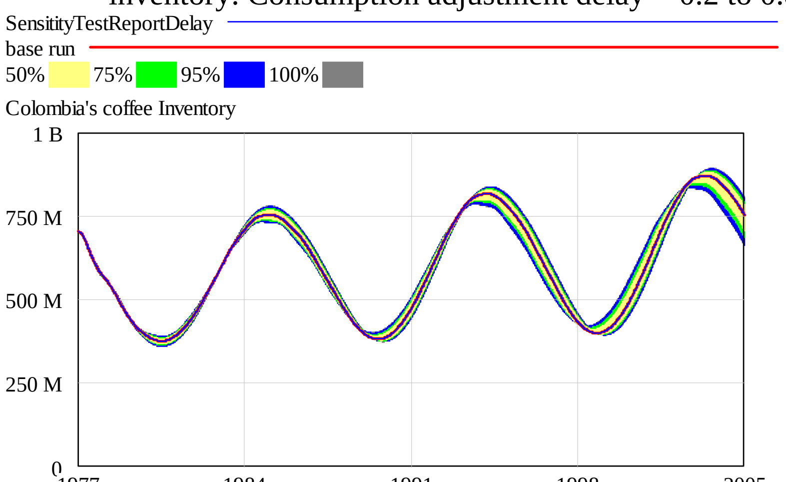


Figure 54. Parameter sensitivity test: Colombia’s coffee inventroy Time to adjust price = 0.1 to 1

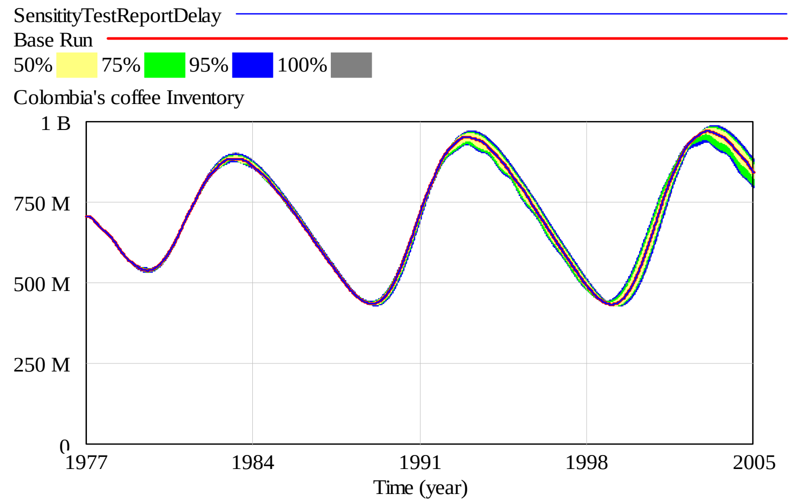


Figure 55. Parameter sensitivity test: Colombia´s Coffee inventory Report delay = 0.02 to 0.18

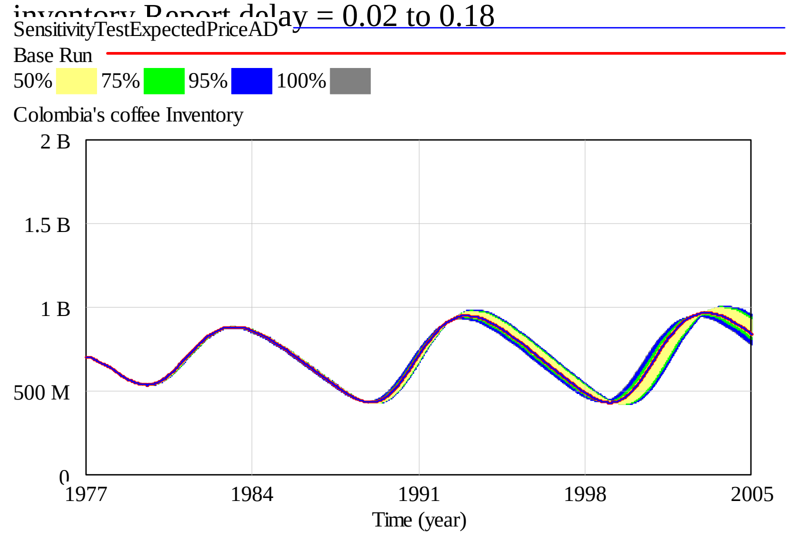


Figure 56. Parameter sensitivity test: Colombia’s coffee inventroy Expected Price AD = 0.02 to 0.3

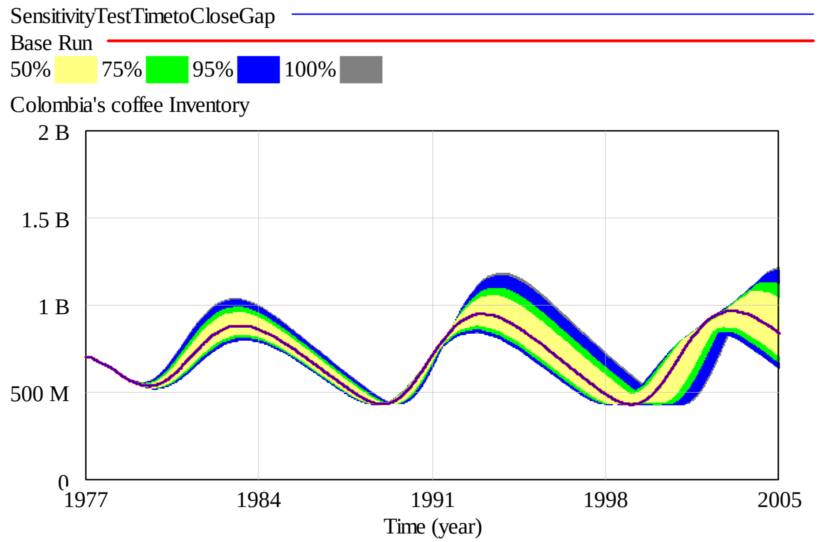


Figure 57. Parameter sensitivity test: Colombia’s coffee inventory Time to Close gap = 0.3 to 0.7

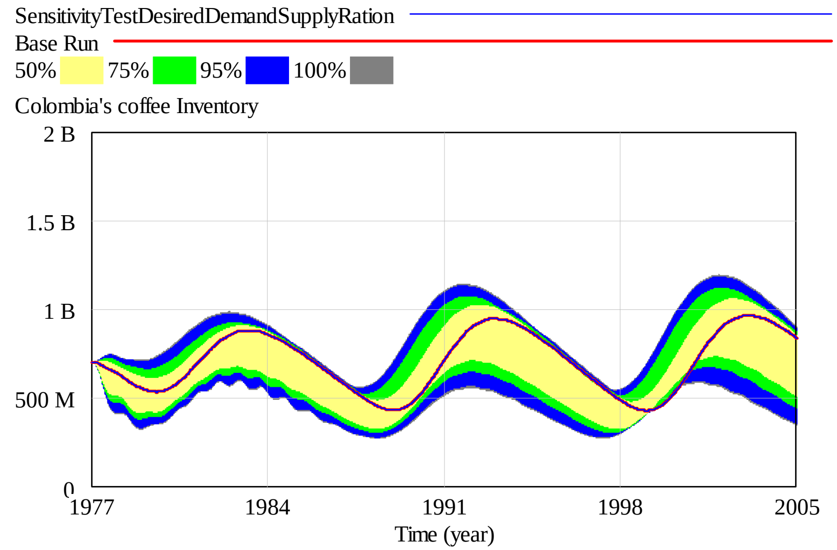


Figure 58. Parameter sensitivity test: Colombia’s coffee inventory Desired Supply demand Ratio = 0.5 to 0.1

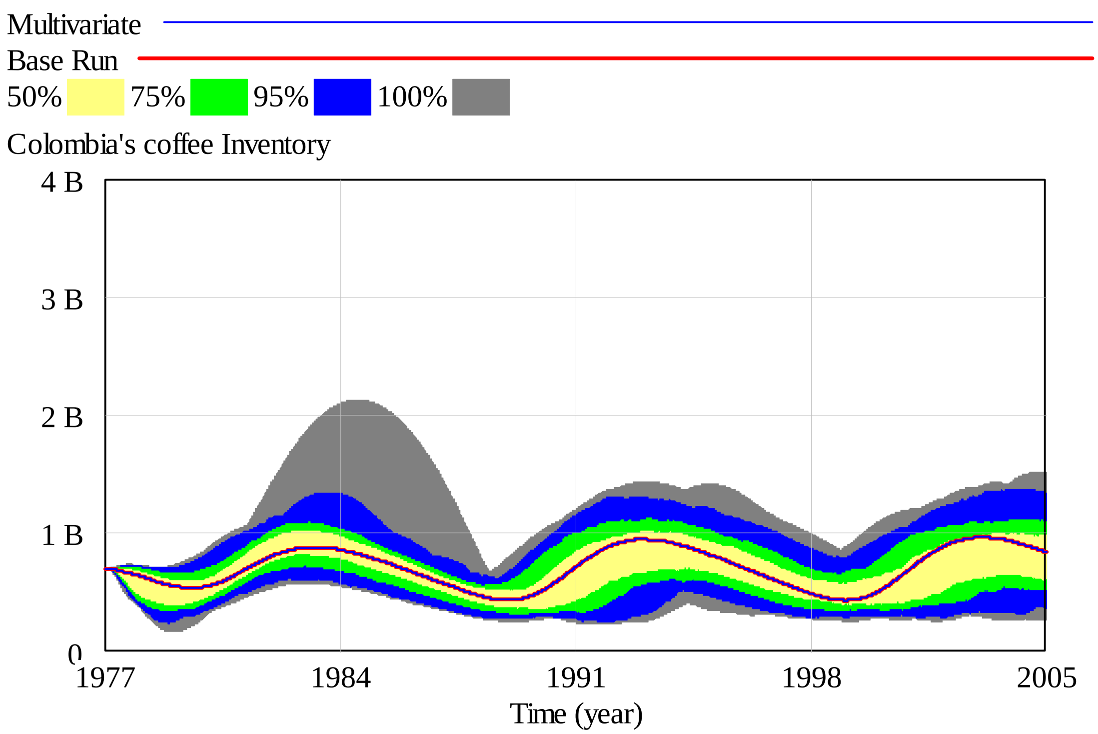


Figure 59. Parameter sensitivity test: Colombia’s coffee inventory Multivariate

Extreme condition test

The purpose of this test is to see how robust our model is and, see how it behaves under extreme conditions like no consumer population or productive capacity equals zero.

No consumer Population

Assume no one wants to consume coffee, so both Colombia’s consumer population and consumer population are equal to zero and remain zero during the simulated period.

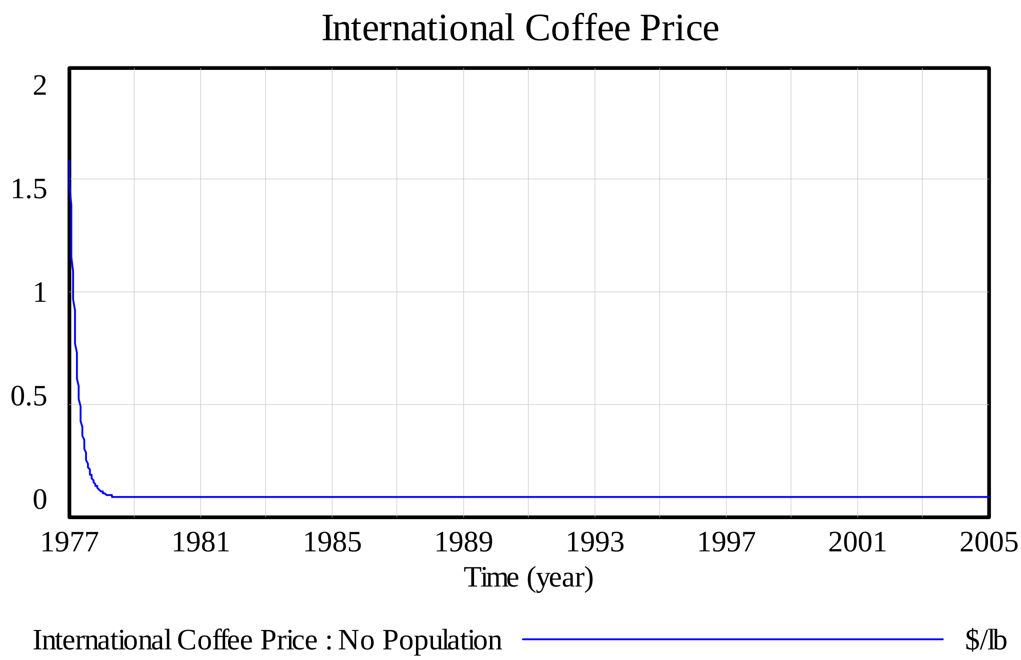


Figure 60. Extreme condition test: International Coffee price when consumer population = 0

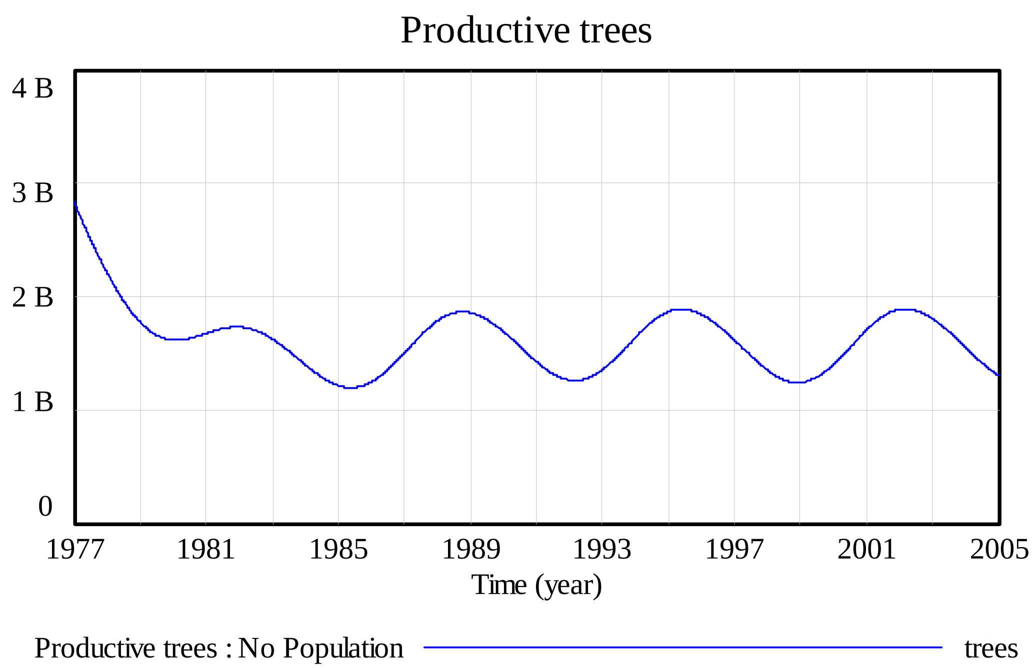


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Figure 61. Extreme condition test: Productive Trees when consumer population = 0

Figure 60. and Figure 61., show the results for International Coffee price and Productive trees when consumer populations (International and domestic) are equal to zero. The international coffee price goes down to zero because there is still coffee production but there is no one to buy it (Demand). Productive trees keep oscillating around 1.5 Billion coffee trees because the minimum price policy maintains the expected coffee price at the same level all the time and therefore the desired number of coffee is always the same

No Productive trees

In this test we assumed there are no productive trees at the beginning of the simulation. Figure 62. shows the behavior of the productive trees stock during the simulated period. It shows how the productive trees stocks start at zero and therefore production decreases, inventory decreases and price quickly increases (because coffee inventory is being quickly depleted for the lack of production). At high price the attractiveness to sow new trees also increases and therefore the productive trees stock but because of the time it takes for a tree to become productive, farmers over-build capacity and consequently there is an overproduction of coffee causing a decrease in price again.

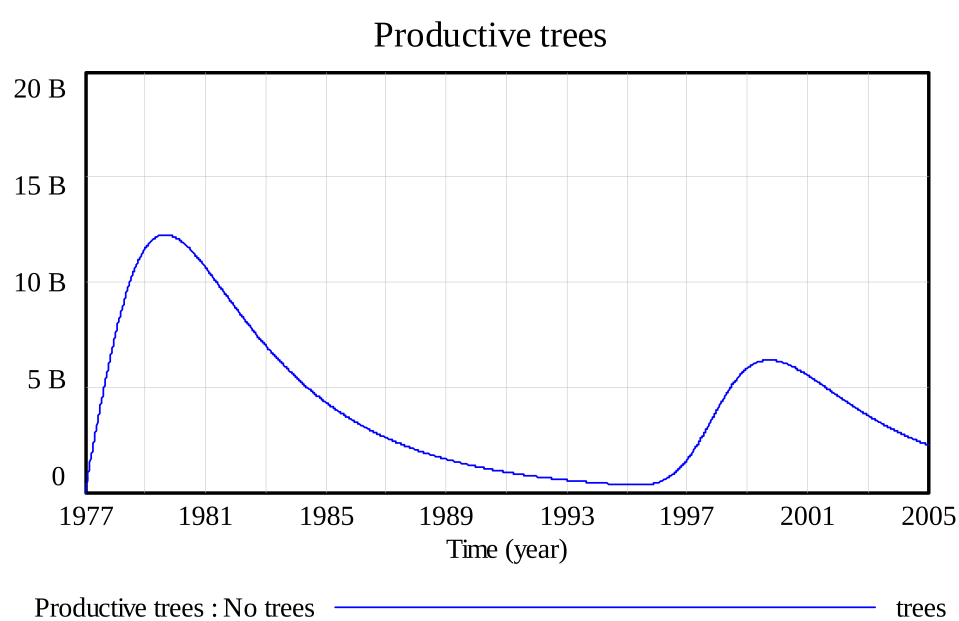

Figure 62. Extreme condition test: Productive Trees when Productive trees = 0

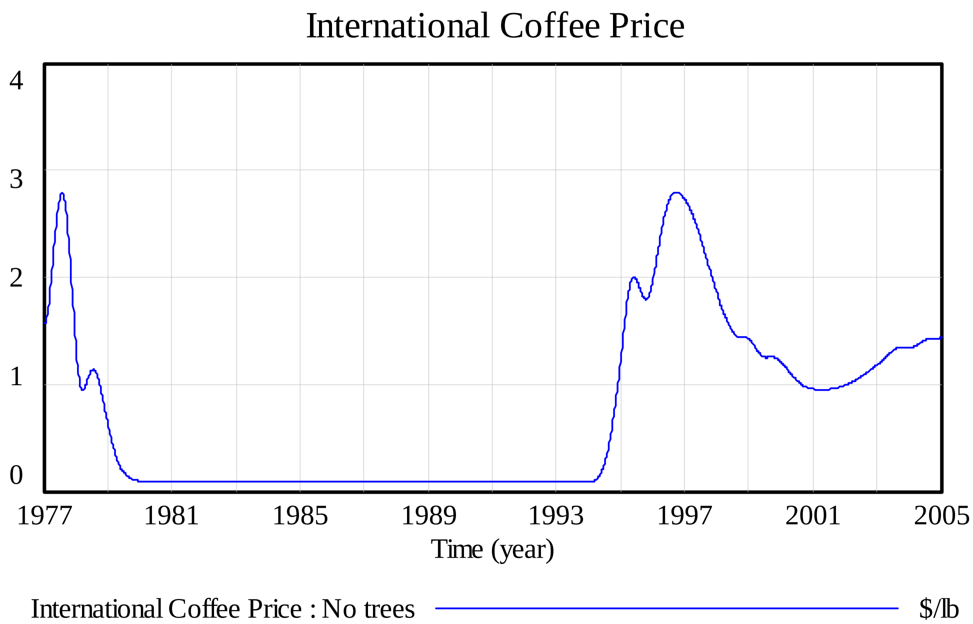

Figure 63. Extreme condition test: International coffee price when Productive trees = 0

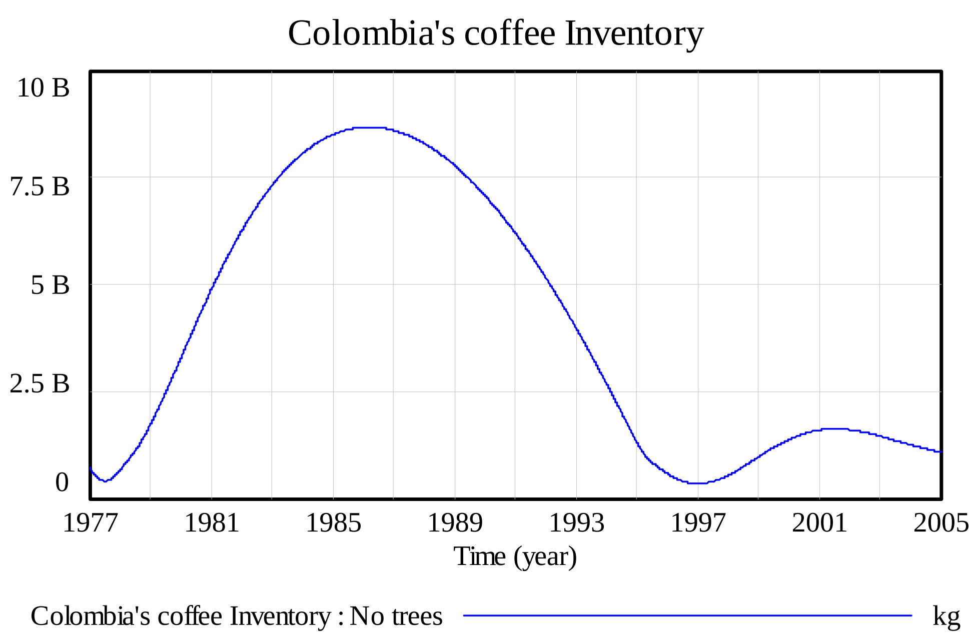

Figure 64. Extreme condition test: Colombia’s coffee inventory when Productive trees = 0

Appendix 3 Behavior Test

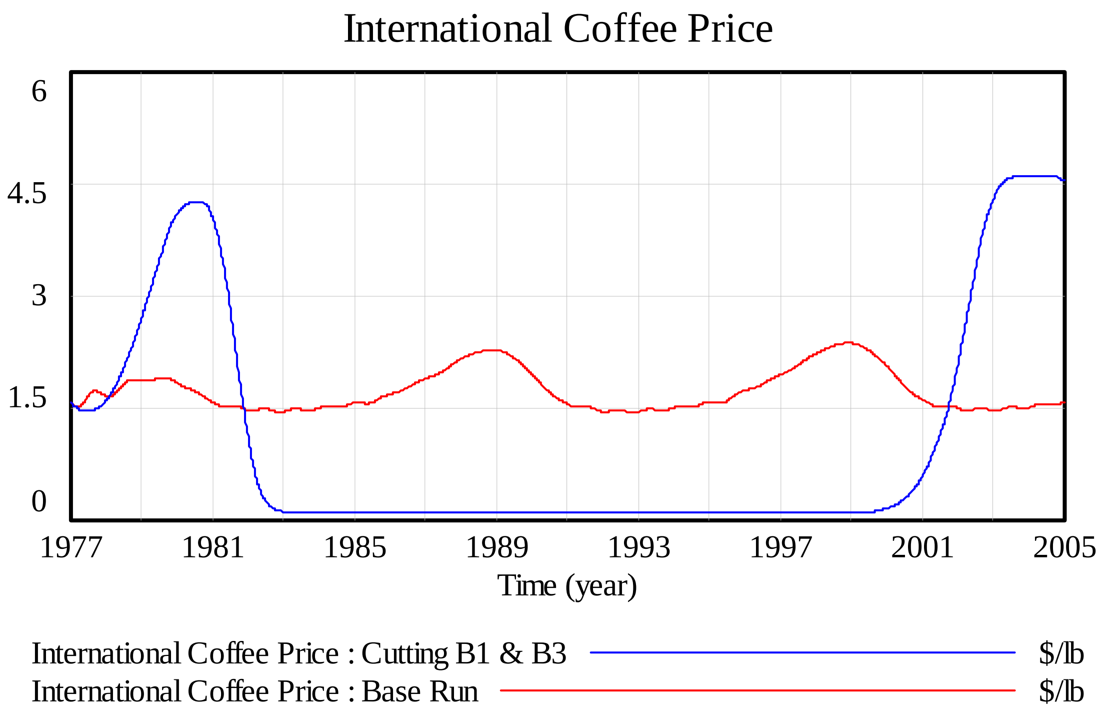

Figure 65. Behavior test: Cutting B1 an B3 by making consumption adjustment delay extremely big (1e+006)

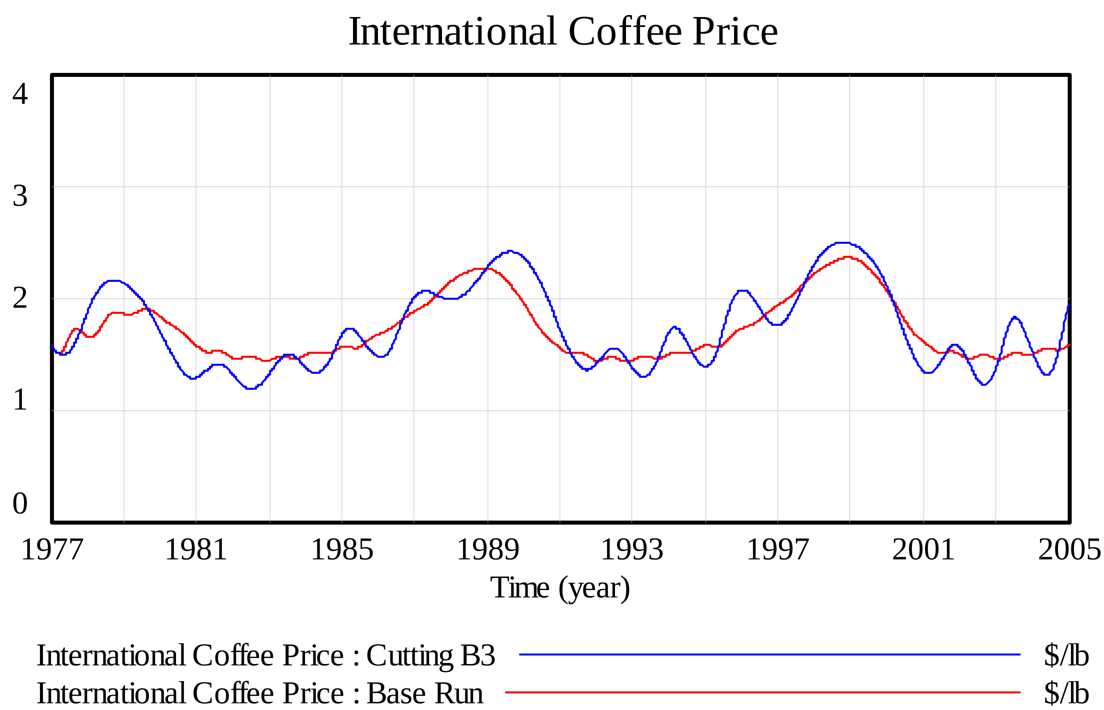

Figure 66. Behavior test: International coffee price Cutting C3 by making report delay (adjustment time) very big (1e+006)

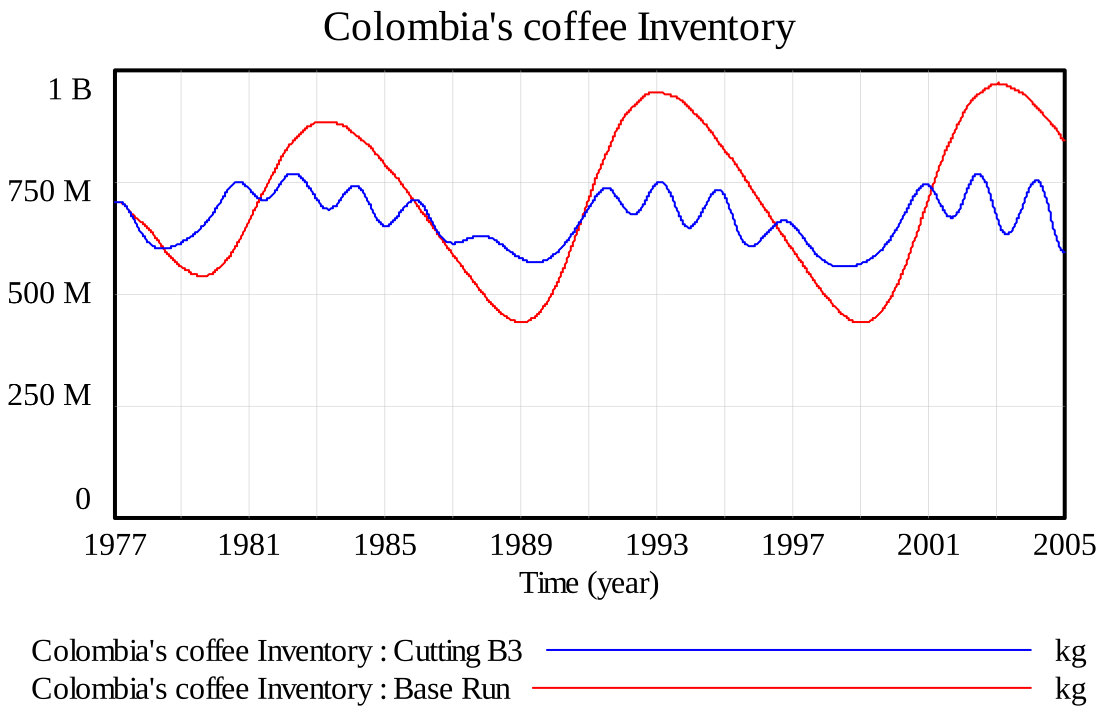

Figure 67. Behavior test: Colombia's coffee inventory Cutting C3 by making report delay (adjustment time) very big (1 e+006)

Appendix 4 Model Equation

Third age productive trees= INTEG ("re-grow 2"-disposable trees, 2.5646e+008)
~ trees
~ 2.5646e+008

Max Shipment= Colombia's coffee Inventory/minimum order processing time
~ kg/year|

Minimum order processing time= 2/12
~ year

Colombia's Coffee Exports= min(International Demand for coffee*Other things affecting Exports,Max Shipment)
~ kg/year

Desired Number of productive trees= Reference trees*Effect of Expected Price on Desired number of trees(Relative Expected Price)
~ trees

Reference trees= 4.339e+009
~ trees

Reference Mode=
ref mod 2(Time)/100
~ $/lb

Production Initiation Rate= (Productive trees)*"Average Yield mt/tree new trees"+(Second age productive trees+third age productive trees)*"Average Yield mt/tree old trees"
~ kg/year

"Average Yield mt/tree old trees"= 0.1
~ kg/trees/year

Colombia's Coffee Consumption Rate= Colombia's Per Capita Consumption*Colombia's Consumer Population(Time)
~ kg/year

disposable trees= third age productive trees/Average Life Time
~ trees/year

"re-grow 2"= no productive trees 2/"Average time to re-grow"
~ trees/year

productive trees gap= Desired Number of productive trees-Productive trees-Second age productive trees-third age productive trees

~ trees

no productive trees 2= INTEG (disosable trees rate-"re-grow 2", 1.7578e+008)
~ trees

no productive trees= INTEG (+withdrawals from productive trees-"Re-growing rate", 3.9825e+008)
~ trees
~ 3.9825e+008

Trees growing stock= INTEG (sowing new coffee trees-new trees to productive trees transition rate, 1.436e+009)
~ trees
~ 2.436e+009

Minimum price= 1.5
~ $/lb

Relative Expected Price= Expected Coffee Price/Initial Market Price
~ dmnl

Supply Demand ratio= (Colombia's coffee Inventory)/Average Consumption Rate
~ year

International Demand for coffee= Consumer Population(Time)*Coffee PCC Importing countries
~ kg/year

Average Life Time= 3
~ year

disosable trees rate= Second age productive trees/Average Life Time
~ trees/year

Second age productive trees= INTEG (+"Re-growing rate"-disosable trees rate, 1.205e+009)
~ trees

"Average time to re-grow"= 1
~ year

"Average Yield mt/tree new trees"= 0.25
~ kg/trees/year
~ http://www.lablaa.org/blaavirtual/economia/cafecari/cafe3.htm

"Re-growing rate"= no productive trees/"Average time to re-grow"
~ trees/year

sowing new coffee trees= max(0,(productive trees gap)/time to close the gap)
~ trees/year

new trees to productive trees transition rate= DELAY3(sowing new coffee trees,time to become productive)

~ trees/year

Average time to cut tree= 4

~ year

Coffee PCC Importing countries= INTEG (Per Capita Consumption Change Rate, Initial per capita consumption)

~ kg/year/person

Coffee Production Rate= DELAY3(Production Initiation Rate, Production Delay)

~ kg/year

Colombia's coffee Inventory= INTEG (Coffee Production Rate-Colombia's Coffee Consumption Rate-Colombia's Coffee Exports, Initial Coffee Inventory)

~ kg

Colombia's Consumer Population ([(1976,0) - (2042,8 e+ 007)],(1977,2.64922e+007), (1978,2.71064e+007) , (1979,2.77286 e+007) \ (1980,2.83556e+007),(1981,2.89872e+007), (1982,2.96242e+007),(1983,3.02662e+007),(1984,3.0913e+007),(1985,3.15641e+007),(1986,3.22192e+007),(1987,3.28779e+007),(1988,3.35401e+007),(1989,3.42056e+007),(1990,3.48745e+007),(1991,3.5546e+007),(1992,3.62197e+007),(1993,3.68959e+007),(1994,3.75755e+007),(1995,3.82586e+007),(1996,3.89448e+007),(1997,3.96327e+007),(1998,4.03202e+007),(1999,4.10043e+007),(2000,4.16826e+007),(2001,4.23545e+007),(2002,4.30193e+007),(2003,4.36745e+007),(2004,4.43173e+007),(2005,4.49458e+007),(2006,4.55584e+007),(2030.86,6.27723e+007))

~ person

Colombia's Per Capita Consumption= 0.5

~ kg/person/year

Consumer Population([(1976,6e+008)-(2010,1e+009)],(1977,7.17981e+008) ,(1978,7.22694e+008),(1979,7.28948e+008),(1980,7.35482e+008),(1981,7.40193e+008),(1982,7.44413e+008),(1983,7.48351e+008),(1984,7.52068e+008),(1985,7.5601e+008),(1986,7.602e+008),(1987,7.64244e+008),(1988,7.68527e+008),(1989,7.73544e+008),(1990,7.78846e+008),(1991.28,7.84818e+008),(1992.34,7.90099e+008),(1993.49,7.967e+008),(1994.28,7.9934e+008),(1995,8.05334e+008),(1996.4,8.11221e+008),(1997.28,8.15182e+008),(1998,8.17822e+008),(1999.58,8.25743e+008),(2001,8.32343e+008),(2002.23,8.38944e+008),(2003.91,8.49505e+008))

~ person

Consumption Adjustment Delay= 0.3

~ year

Desired Supply Demand Ratio= 0.8

~ year

difference between actual and average CR= Colombia's Coffee Exports-Average Consumption Rate

~ kg/year

Effect of coffee price on PC Consumption([(0,0)-(3.2,2.5)],(0,2),(0.2,1.95),(0.4,1.85),(0.6,1.76),(0.8,1.58),(1,1),(1.2,0.82), (1.4,0.7),(1.6,0.59),(1.8,0.52),(2,0.48),(3,0.25))
~ dmnl

Effect of Expected Price on Desired number of trees([(0,0)-(2.1,2)],(0,0.51),(0.2,0.52),(0.4,0.55),(0.6,0.63),(0.794805,0.759076),(1,1),(1.16881,1.17544),(1.39358,1.32456),(1.57339,1.42982),(1.78182,1.47368),(1.9844,1.47368))
~ dmnl

Effect of Inventory Coverage on Net Change([(0,-0.5)-(4,4)],(0,3),(0.25,2.90429),(0.5,2.64026),(0.75,1.83498),(1,1),(1.21101,0.565789),(1.34557,0.328947),(1.54128,0.131579),(1.76147,0.0526316))
~ dmnl

Indicated Per Capita Consumption= Initial per capita consumption*Effect of coffee price on PC Consumption(International Coffee price Index)
~ kg/year/person

Expected Coffee Price= INTEG (Expected Price Change Rate, 1.558)
~ $/lb

Report delay= 0.1
~ year

Expected Consumption Change Rate= difference between actual and average CR/Report delay
~ kg/year/year

Average Consumption Rate= INTEG (Expected Consumption Change Rate,8.4828e+008)
~ kg/year

Expected Price Adjustment Delay= 0.1
~ year

Expected Price Change Rate= IF THEN ELSE(International Coffee Price<Minimum price, (Minimum price-Expected Coffee Price)/Expected Price Adjustment Delay,(International Coffee Price-Expected Coffee Price)/Expected Price Adjustment Delay)
~ ($/lb)/year

Indicated Price= Initial Market Price*Effect of Inventory Coverage on Net Change(Relative Demand Supply Ratio)
~ $/lb

Initial Coffee Inventory=7.0517e+008
~ kg

Initial Expected Consumption Rate= Initial Expected Consumption Rate mton*Conversion Factor Mtons to Kg
~ kg/year

Initial Expected Consumption Rate mton= 2.5e+006
~ mton/year
~ Agriculture and Food -- Resource Consumption: Coffee consumption

Initial number of productive trees= 2.47451e+009/2
~ trees

Initial Market Price= 1.5772
~ $/lb

Initial per capita consumption= 1.169
~ kg/(year*person)

International Coffee Price= INTEG (net change in coffee price,Initial Market Price)
~ $/lb

Productive trees= INTEG (new trees to productive trees transition rate-withdrawals from productive trees, 2.835e+009)
~ trees

net change in coffee price= (Indicated Price-International Coffee Price)/time to adjust price
~ $/lb/year

Per Capita Consumption Change Rate=(Indicated Per Capita Consumption-Coffee PCC Importing countries)/Consumption Adjustment Delay
~ kg/year/person/year

Production Delay=0.2
~ year

Relative Demand Supply Ratio= Supply Demand ratio/Desired Supply Demand Ratio
~ dmnl

International Coffee price Index= International Coffee Price/Initial Market Price
~ dmnl

ROW Coffee Inventory([(1976,0)-(2010,4e+009)],(1977,1.5219e+009),(1978,1.6197e+009),(1979,1.53324e+009),(1980,1.73634e+009),(1981,1.69404e+009),(1982,2.54358e+009),(1983,2.44344e+009),(1984,2.5314e+009),(1985,2.15178e+009),(1986,2.0823e+009),(1987,2.10174e+009),(1988,3.27642e+009),(1989,3.33102e+009),(1990,2.9817e+009),(1991,2.7711e+009),(1992,2.78202e+009),(1993,2.69586e+009),(1994,2.63718e+009),(1995,2.87352e+009),(1996,2.2788e+009),(1997,2.28072e+009),(1998,2.18124e+009),(1999,2.28528e+009),(2000,3.16884e+009),(2001,3.1308e+009),(2002,2.79432e+009),(2003,3.06858e+009),(2004,2.40894e+009),(2005,2.19966e+009),(2006,1.6455e+009),(2007,1.43022e+009))
~ kg

time to become productive= 2
~ year
time to adjust price= 0.25
~ year

time to close the gap= 0.5
~ year

withdrawals from productive trees= Productive trees/Average time to cut tree
~ trees/year