Honey Agri-food Chain in Argentina: Model and Simulation

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Abstract

This work will show the dynamics involved in the study of the honey agri-food chain in Argentina. The method explained would show how to model and simulate complex feedback mechanisms allowing the behaviour analysis of a determined system over a period of time. These simulations will allow quantitative predictions for future scenarios to take place, being a useful tool to test diverse policies.

We chose the honey agri-food chain as our study objective since it's a simple product. It does not require industrial processing and is an export-oriented activity.

The system model is elaborated from a causal loop diagram, and after comparing some variables of interest with historical series; simulations are made in order to determine the impact of diverse future scenarios, like the effect of the devaluation, China behaviour in markets, and climatic and technological scenarios.

The relation of system dynamics and supply chain management is reviewed, and the usefulness of system dynamics as a tool for predicting different scenarios and for supply chain redesign is highlighted.

Résumé

Ce travail illustre les dynamiques impliquées dans l'étude de la chaîne agro-alimentaire du miel en Argentine. La méthode présentée illustre comment modéliser et simuler les mécanismes de feedback qui permettent l'analyse du comportement d'un système dans une période de temps donnée. Ces simulations permettront des prévisions quantitatives de l'occurrence de scénarios futurs ; ceci étant un instrument utile pour tester différentes politiques.

La chaîne agro-alimentaire du miel a été choisie en tant qu'objet de notre étude car il s'agit d'un produit simple. Il ne requiert aucune transformation industrielle et il s'agit d'une activité orientée à l'exportation.

Le modèle de système est élaboré à partir d'un diagramme de causalité, et après avoir comparé certains variables d'intérêt avec des séries historiques, les simulations sont faites afin de déterminer l'impact de différents scénarios futurs, tel l'effet de la dévaluation, le comportement de la Chine dans les marchés ainsi que les scénarios climatiques et technologiques.

1. Introduction

Agrifood chains are a particular case among supply chains (SC). We define a SC as a group of economic entities (suppliers, producers, distributors) that work together to acquire raw materials, produce goods, and deliver these goods to consumers. (Beamon, 1998) These chains are characterized by a forward flow of materials (producer-consumer) and backward information flow. Over the past years, the processes involved in the SC have been investigated separately. Nevertheless, there has been an increased interest in studying the performance, design and analysis of the SC as a whole.

The complexity of the system requires a multidisciplinary approach, and the consequent generated models use a large variety of techniques and tools. These models can be classified in several ways: static or dynamic, stochastic or deterministic, analytical or numerical, discrete or continuum, for optimization or simulation.

Dynamic models allow us to examine the SC behavior as a response to changes in the external chain environment. One of the possible approaches is constituted by a model representing the SC as a system of discrete events. Interesting results with this technique, including diverse aspects of uncertainty in different parameters of the chain, were obtained by Southall and collaborators (Southall et al., 1998), Petrovic, (Petrovic, 2001) and particularly by Van der Vorst (Van der Vorst, 2000), who evaluated the performance of a food SC in different scenarios.

The continuum dynamic models used to study the SC are based on the system dynamics methodology (Forrester, 1961). This technique has been used in the analysis of diverse aspects of the SC, the international management of SC's (Akkermans et al., 1999), redesign strategies by market changes (Towill, 1996), and benefits optimization and costs reduction in three stages chains (Barlas and Aksogan, 1997). Because they involve multiple chains of stocks and flows, with the resulting time delays, and because the decision rules governing the flows often create important feedbacks among the partners in the SC, system dynamics is well suited for SC modeling and policy design (Sterman 2000).

We apply the system dynamics methodology in this work to study a specific agrifood chain, in order to describe its operation, and to try to predict the behavior in several future scenarios over a period of five years.

We chose Argentinean honey as our agrifood chain of analysis. Argentina is the third leading honey producer after China and Mexico having reached first place in exports during the year 2000. It generated over US$

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87,000,000 in profits; mainly due to increased and sustained production and a low national consumption. We restricted ourselves to bulk commercialized honey since it does not require industrial processing, and this is the main reason why we chose this agrifood chain. We also chose it since it's strongly oriented for exportation.

The apicultural sector is part of the Argentinean agro-industrial complex, which in turn includes more than half of the country's external sales. For this reasons, the availability of diagnosis, analysis and prediction tools that contribute to the decision making in policy design are of strategic importance.

2. System Dynamics and Supply Chains

Several authors have applied system dynamic tools, firstly to the study of SC performance. A classic and intuitive presentation of systemic consequences of managerial actions in successive stages of a SC is the Beer Distribution Game, developed at MIT's Sloan School of Management in the US (Forrester 1958; 1961). The game consists of 4 SC stages: retailer, wholesaler, distributor and producer. The game is designed in order that each actor has limited information about inventory levels and orders to be placed by the other actors, and also there are delays between orders and shipments. When this game is played, the outcome is that huge order fluctuations and demand amplification take place in the SC. Orders to the supplier tend to have larger variances than orders from the buyer, being the distortion propagated upstream in an amplified form, phenomena known as Forrester effect or Bullwhip effect.

To reduce the above mentioned demand amplification, it was suggested by several authors that all time delays in good and information flows should be minimized, and that each actor should know the true market demand to improve the decision rules at each stage of the SC (Van der Vorst 2000). This author also presented a step-by-step approach to generate, model and evaluate supply chain scenarios. After defining the system boundaries, objectives and SC key performance indicators, he devised an approach to identify sources of uncertainty and to identify potentially effective SC scenarios as well. By means of this approach, a methodology for generating, modeling and evaluating SC scenarios is created. However, he utilized computational tools based on discrete events to model SC as a network of administrative and physical logistical activities with precedence relations in time, in order to capture the dynamic behavior of the SC process.

A SC is a complex structure composed of several elements heavily interconnected, and in which product and information does not flow instantaneously, but having delays which can be of consideration.

In the bibliography, the SC is generally analyzed considering ties between players limited to orders, delivery delays and shipments. However, players are reluctant to share other type of information. This is because each player adjust its orders empirically on the basis of its best understanding of delays along the SC. If each player would know the actual order rates of the others, it would be hard to manipulate orders to get the desired quota of materials when delays are long (Sterman 2000).

Usually bottlenecks are encountered in SC, arising from imbalances between growth of production, processing industry, retail and consumer preferences, as reported in the case of a System Dynamics study on the dutch organic food chains (Schepers 2002). This could be the case of Argentinean honey chain, where demand largely exceeds production. System Dynamics was also applied to the study of changes of supply and demand in the pork chain under different coordination mechanisms (Sonka and Cloutier, 1998). These authors reported that a three period 5% step decrease in supply required 28 months to stabilize the system under an informational feedback coordination mechanism, while 35 months were needed to stabilize the system under a price coordination mechanism. They also presented different scenarios for supply (base case and high frequency fluctuations) and demand (linear or oscillating), concluding that faster transmission of information makes a difference when demand begins to oscillate (considering an scenario of high frequency supply fluctuations and oscillating demand growth).

Apart from the above mentioned advances in agrifood SC modeling, in aggregated SC, state policies are the main ones that should watch over for a proper functioning of an agrifood chain. In Argentina, the unstable institutional frame hampers chain competitiveness, although the devaluation in late 2001 lead to artificial increase in competitiveness as a results of a more real exchange rate. Also, very often is difficult for public officials to deliver regulations which can benefit a player in the chain without affecting another one. For example, export promotion implemented by Argentine Government in 2002 could benefit exporter profits while overlooking primary producers. Honey chain has to change from an old paradigm of transactional behavior to a more interactive, relationship based and network-like relational paradigm (Lindgreen and Beverland 2002) which can take account of far-off players from consumer in the chain, who are the ones that bear the worse part of chain instability and order oscillations, as described above.

3. System Dynamics and Supply Chain Management

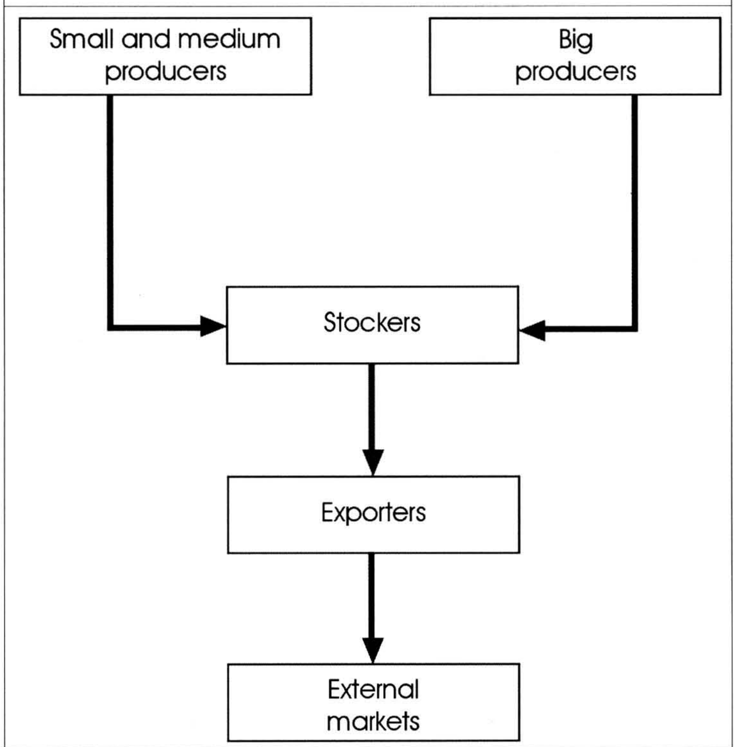
System dynamics modeling in Supply chain management (SCM) was previously reviewed (Angerhofer and Angelides, 2000). They presented a taxonomy of research and development based in five categories of research areas: inventory management, demand amplification (which was described in the previous section), supply chain re-engineering, supply chain design and international SCM. Since the first published work in System Dynamic Modeling related to SCM of Forrester in 1958, little efforts were made on developing System Dynamics, as stated by Towill, who argued that the use of industrial dynamic modeling of real-life SC has only recently emerged from the shadows after a lengthy gestation period (Towill 1996a). In recent years, a more integrated approach was attempted to study the SCM from the an international management focus of SC (Akkermans et al., 1999). This supposes the existence of a clear focus on integration and co-ordination for better profitability and customer service. Supply chain design is an important factor so as to managers can optimize the allocation of resources for achieving profits maintaining quality. For example, when firms grow, they face the decision of increasing its actual production of the plant or to expand by building new ones. This is a typical example of a decision-making problem, which will evolve in a new SC design, and where System Dynamics can help in order to support manager decision in a quantitatively manner. In this sense, System Dynamics proved to be an useful tool for considering soft variables (for example, motivation, skills), which otherwise are not taken in account at all in other frameworks of analysis. Supply chain re-engineering will be briefly tackled in the next section.

3.1. Trust, Redesign and Reengineering S-trategies in the Supply Chain

Trust among partners of a SC is an important condition for an efficient redesign. Without trust among partners, the conflict and mistrust created by naturally occurring SC instability feed back to worsen the instability in a vicious cycle (Sterman 2000).

Honey export initiatives in Argentina surged from groups of action which utilized efficiently government help through subsides. For example, in Santa Fe province a group nucleated into a cooperative, allowing small honey producers access to costly machines for accomplishing international food safety standards. Cooperative management contributed to coordinate production, l-ogistics and distribution steps, in a naturally e-merged approximation to a SCM approach. This could not be done without trust among partners and making use of existing assets and social capital.

Figure 1. *Simplified flow diagram*



Quality, customer service level, total cost and lead time are the key variables to consider when redesigning SC. The main reengineering strategies reported for SC are based in the optimization of these components, founded in minimizing lead times, reducing delays and consequently total costs (Towill, 1996b). In order to measure the performance of redesigned chains compared with others, construction of indicators for SC benchmarking has been reported (Johansson et. al. 1993, in Angerhofer and Angelides 2000), in this case using these four components: they quantitatively defined performance in SC as quality times customer service level divided by total cost times lead time. SC modeled using System Dynamics are convenient for assessing the results of redesigned policies, as it is possible to quantitatively predict several scenario outcomes, evaluating its performance with respect to the selected variables.

4. Methodology

We apply the system dynamics methodology. It allows us to analyze the behavior of a system over time. This method allows approaching problems related to nonlinear complex systems with feedback loops. Basically, it consists of a system model representation made up by two main elements: stucks and flows. The stocks consist of levels that can increase or diminish only gradually in time, in function of the respective inflows and outflows, which in turn depend on the available information (through auxiliary variables) and stocks. The model is completed by auxiliary variables and functional relationships.

The necessary steps for the construction and use of the model are:

1. Information survey relative to material and information flows (production, distribution economic, etc.) Causal loop diagram (CLD) construction for the model.
2. Mathematical formalization (stock and flow diagram SFD) and model validation.
3. Possible future scenario simulations.

These three steps are not independent, since it is often necessary to go back to make corrections or adjustments.

5. Results

5.1 Argentinean Honey Agrifood Chain Overview

Beekeeping in Argentina has grown over the last twenty years, duplicating its production in the last ten years. Bulk exported honey experienced the same growth, with Argentina becoming the world's leading exporter in the year 2000. This growth is justified by the increasing global demand for the product and the rise in local production.

The productive sector is made up by nearly 25,000 producers, and they usually are not devoted to honey production as their main source of income . Due to the quantity and scale of producers, the stockpilers have an important function in this chain because they concentrate honey production and sell it to the domestic market or exporters. The commercialization and distribution channels for honey are strongly oriented to the external market. Generally, honey is exported as a commodity. The mainstream showed in Figure 2, involves approximately 80% of total production.

5.2 System Definition

We are interested in the analysis of the SC export performance, in several scenarios. Since 95% of the produced honey is exported, we build the model based on the flow diagram (Figure 1). In all cases, our horizon extends to five years.

The actors included in the system are:

- Small and medium producers
- Big producers
- Stockpilers
- Exporters

The producers set the number of productive hives; we have grouped them in small and medium producers in one side, and big producers on the other, considering their differences in costs, yields and prices due to their scale of production. The honey is delivered to stockers, who sell it to exporters. Then, exporters send the honey to the external markets. The feedback mechanism is composed by information that travels upstream in the chain. Basically, this information is based on prices and demand.

All feedback systems have a closed boundary; inside this limit a distinct behavior is generated. This limit is established when the system variables are classified as endogenous or exogenous. Endogenous variables are included in feedback loops, and are determined by the dynamics of the system. The exogenous variables are not affected by the system′s behavior, and generally are constants or variables in time.

5.3 Model Assumptions

The construction of models that represent to some degree the complex reality requires assumptions originated by the necessity to simplify the involved processes; or also in the lack of information about specific aspects that affect the system′s dynamic.

How we elect model assumptions is very important, since the system's behavior is derived from them. For this reason, assumption specification is generally made up of a balance between the degree of realism and simplification required. Next, we detailed the main assumptions of this work:

1. External demand: We were not able to find information about the real external demand for honey in the available databases. However, from consulted experts, we estimate that a higher demand exists than the actual production capacity (more than twice the current demand). We used as a minimum estimation the historical exportation series.
2. Prices: In our model we establish three different prices, the external Free on Board price and two inner prices. We assume that Argentina is not a price forming country, so the Free on Board price for honey is considered as an exogenous variable. Regarding the internal prices,

Figure 2. *Correction factor: yield per hive per year due to weather and density of hives*

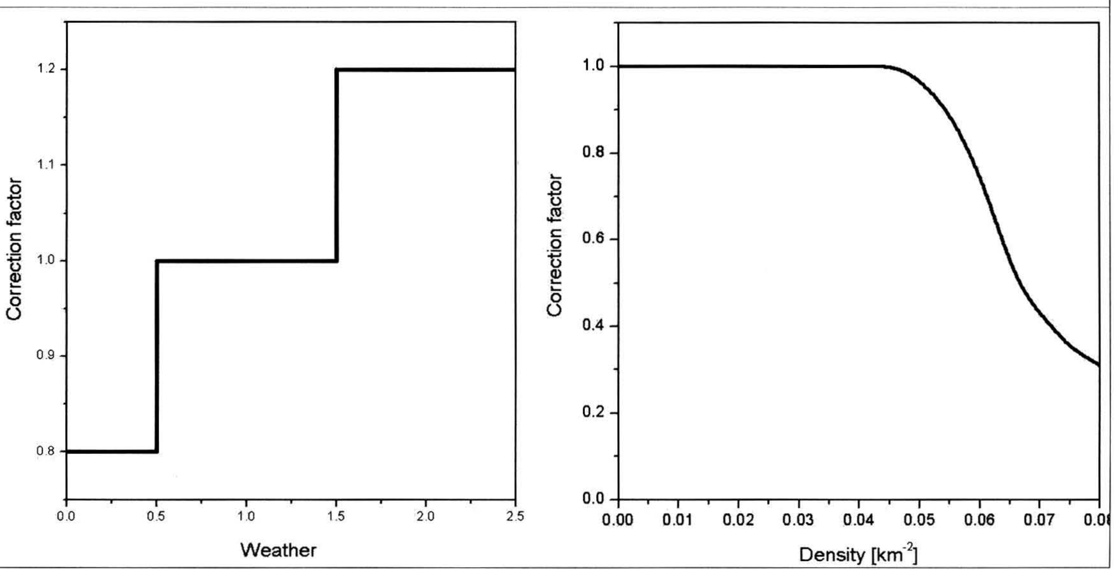
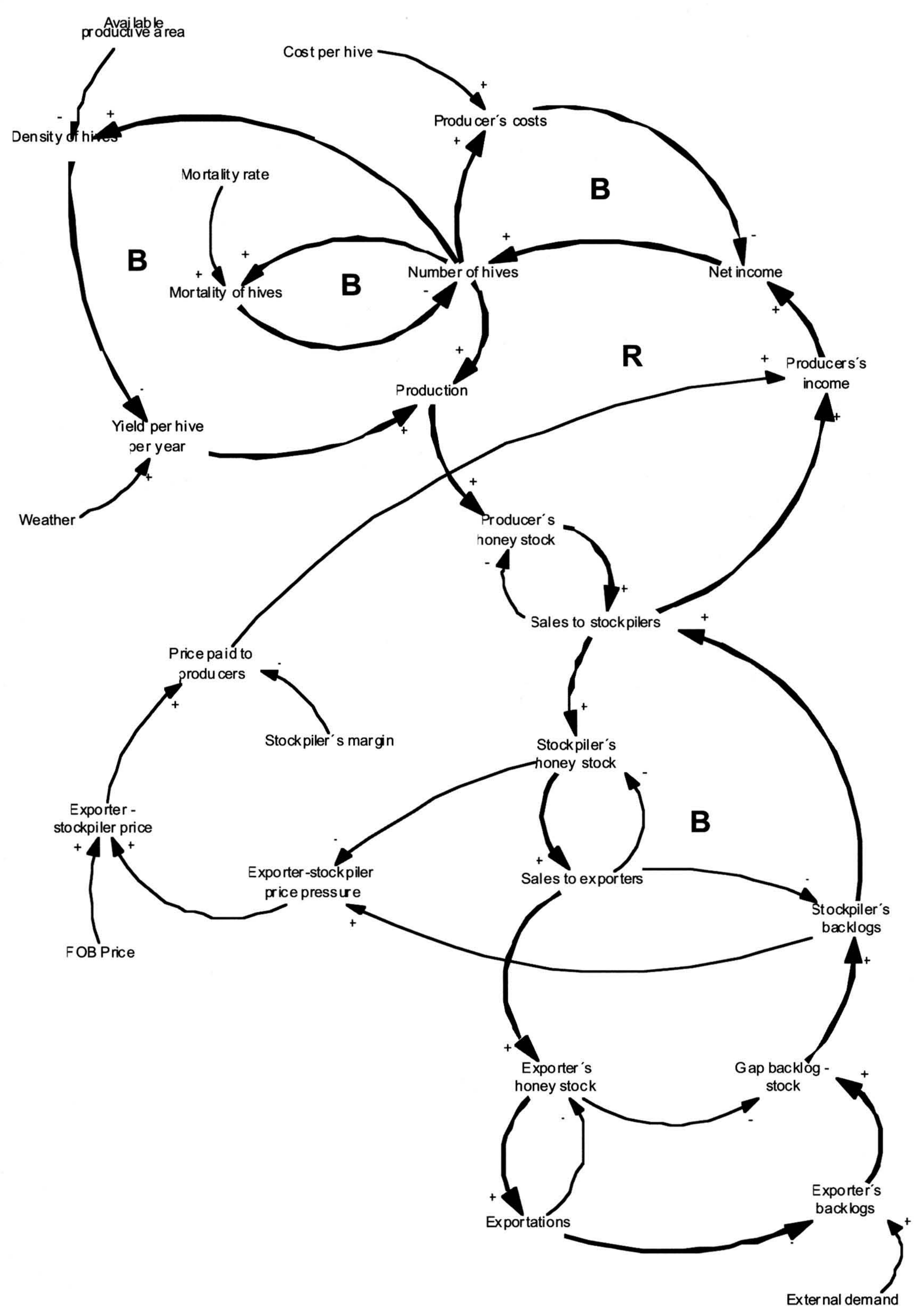


Figure 3. *Simplified CLD for the honey agrifood chain*



they are established by the price paid to stockers by exporters. It also depends on the ratio backlog/honey stock of stockers. Finally, the price given to producers from stockers is simply the above price minus the stocker margin.

3. Production: The production control variable is established by the number of hives. We state that the producers increase that number as a function of the net income obtained in the previous campaign. The hive mortality diminishes the number of productive hives.

4. Yield: In this model, the yield per hive per year depends on two factors. The most important one is climate. The current relationship between yield and weather is not known due to the complexity of this phenomena. We made the following simplification: we consider a three state level for weather: Bad (0), Regular (1) or Good (2). The corresponding corrective factors to yield are 0.8, 1 and 1.2, respectively. Another factor that affects the annual yield is the availability of natural resources. Today, there are about 2.8 million hives, and estimations state that the achievable number could be approximately 4.5 million. This system growth limitation is considered by a saturation function depending on hive density distributed in the productive areas. Both functions are shown in Figure 2.

5.4 Casual Loop Diagram

Casual loop diagrams (CLD) are an important tool to represent the system's feedback structure. These diagrams allow the graphical representation of cause and effect processes that originate in the dynamic behavior. In CLD notation, the arrows

Table 1. *Comparison between real and simulated data*

Period	Variable	r^2	Mean relative percent difference
1991 – 2000	Number of hives	0.7826	– 5,2%
1996 – 2001	Mean price to producer	0.9799	8,1%
1991 – 2000	Exportations	0.6261	–19.9%

Table 2. *Evolution of hives and exportations from 2002 to 2006, with and without devaluation*

Year	Number of hives		Exportations (MTn)	
	Without devaluation	With devaluation	Without devaluation	With devaluation
2002	2 540 091	2 605 602	106 016	106 016
2003	2 578 573	2 990 316	122 150	102 848
2004	2 614 711	4 761 533	129 899	74 920
2005	2 652 993	4 840 877	126 048	84 198
2006	2 692 365	4 820 535	109 213	74 361

represent causal relationships between the elements that bind, and the sign that they have characterizes the direction for the effect, in relation to the cause. In the honey chain CLD outlined in Figure 3, we included the main factors that affect the system behavior, omitting by simplicity in the presentation the intermediate and auxiliary variables. Furthermore, we emphasized the main feedback loops, indicating their reinforcing or balancing nature.

5.5 Simulation Results

The next step in the modeling process consists of model validation by comparison between its behavior and the evolution of the real system. With this goal in mind, we made simulations starting on January 1st, 1991, and finishing on December 31th, 2001. During this period of time, the number of hives (Parker, 2001), mean price to producers and quantity of exported honey from simulated and real values are compared (source: SAGPyA).

In order to obtain a quantitative estimation of the model accuracy, we perform a regression of simulated vs. real values, in order to calculate the correlation coefficient r^2. These values are shown in Table 1, together with the mean relative percent difference.

One of the main applications for mathematical models is to obtain quantitative predictions. With this objective in mind, we analyzed the system's behavior in four different aspects: the impact of devaluation, China's behavior (main competitor of Argentina), international markets and climatic and technological scenarios.

Due to the amount of future possible situations, we only analyzed each one of the previous scenarios in separately. For all cases, the rest of the parameters are held constant.

The change in the dollar/peso ratio causes great changes in the economical aspects of the chain. We compare the evolution of the number of hives and exportation volume with and without devaluation, from 2002 to 2006 (considering the dollar/peso ratio until May 2002).

Table 2 shows an increase of about 60% in 2004, with respect to the previous year considering devaluation, but when the peso and dollar are equal, the number of hives remained almost constant. The great increase in the number of hives with devaluation produces a saturation of the natural resources, therefore, according to our assumptions, the yield of hives diminishes. This explains the reduction in exports. Although this reduction is lesser in volume compared with the one under convertibility, it is higher when its value is considered.

The devaluation effect (great increase in the number of hives in 2004, and the reduction in export volume) appears in all the studied scenarios. In order to separate this effect from other considered events, it is necessary to make comparisons in relation to certain reference cases. In this work, we choose as a reference case (RC) the evolution of the system's behavior with devaluation.

5.5.1 China's behavior in international markets

China one of the greatest competitors for Argentina in world commerce, not in quality (most of the production has industrial destination), but for its low production costs and its great export volume that affects directly the international honey prices. Unlike Argentina, China exports approximately 50 % of its total production, in comparison with Argentina's 90%. A detailed overview of the Chinese apicultural sector can be seen in Branson and Jiamping (2001) and Parker (2001).

One of the possible scenarios consists of China's reduction in exports. This decrease is based on diverse factors: a) Falling production: In 1991–1999, China's number of

Table 3. *Relative change in the number of hives and exportations with respect to RC, as a result of three different increased Free on Board prices due to an eventual decrease in China's supply*

Year	Number of hives (%)			Exportations (%)		
	5%	15%	30%	5%	15%	30%
2002	– 0.27	– 0.27	– 0.27	– 1.03	– 1.03	– 1.03
2003	– 1.39	– 0.69	0.25	– 14.42	– 17.77	– 20.61
2004	– 3.86	– 0.28	5.37	6.78	– 1.72	– 10.24
2005	2.44	4.81	9.53	– 4.83	– 9.01	– 8.97
2006	2.26	6.98	15.99	– 4.78	– 9.40	– 7.01

Table 4. *Relative change in the number of hives and exportations, with respect to the RC, based on the climatic scenario*

Year	Number of hives (%)		Exportations (%)	
	Bad weather	Good weather	Bad weather	Good weather
2002	– 0.27	– 0.27	– 1.03	– 1.03
2003	– 1.74	– 1.74	– 12.24	– 12.24
2004	– 7.35	– 3.63	– 1.94	26.32
2005	– 3.57	7.21	6.97	– 7.57
2006	– 1.54	4.01	– 23.42	17.57

hives has been reduced by 21%; b) Increase in production costs (increased 32% from 1995); c) Increase in China's domestic consumption, and d) Diverse commercial penalties (dumping case in the United States and sanitary sanction - loss of markets in Europe).

Faced with this scenario, the effect on Argentina from a lessening of China exports is reflected in an increase in honey's Free on Board price. Based on a historical series analysis, it could be concluded that the reduction in China's market causes a price increase between 5 and 30%. We evaluated the future scenario in terms of three set increased prices: 5, 15 and 30%.

Table 3 shows an increase in the number of hives for all cases since 2005, relative to the RC. This causes exports to decrease due to the reduced yield consequence of natural resources scarcity. The final price paid to the producer, for the year 2006, would be $ 3.40, $ 3.74 and $ 4.22, corresponding to the increase in the Free on Board price of 5, 15 and 30%, respectively.

The weather effects, considered in our model in a simplified way, were to diminish, to increase or to leave without changes the annual yield per hive, in cases of bad, good or normal weather, respectively (see Figure 2).

We analysed how the model responds to two opposite climatic scenarios, from 2002 to 2006, one with a majority of bad years and another with a majority of good years, choosing as reference a hypothetical scenario with regular weather each year (corresponding to the weather scenario in the RC). We considered that the present year corresponds to bad weather, since a reduction in harvests is forecasted with respect to the previous year. The results are shown in the table 4.

Table 5. *Relative change in the number of hives and exportations, respect to the RC, based on diverse technological impacts*

	Number of hives (%)			Exportations (%)		
Year	Yield	Mortality	Costs	Yield	Mortality	Costs
2002	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.02	0.02	1.63	- 0.08	- 0.17
2004	1.68	0.71	1.10	6.42	- 0.42	- 2.18
2005	4.12	1.43	3.10	3.59	- 1.00	- 5.71
2006	4.47	1.75	4.01	3.24	- 1.07	- 5.36

Many research programs exist nowadays, directed to improve the hive productivity. The main lines are oriented towards genetic improvement and management of hives, that allows basically, the improvement of sanitary conditions, to reduce mortality, to increase the yield and to diminish costs (Spivak and Reuter, 2001; Danka and Villa, 1998; Danka and Villa, 2000).

In our model we analyzed three scenarios with different technological impacts: mortality reduction, yield increase and diminution of costs, all with a 10% magnitude. As in previous cases, we studied the system behavior until December 2006, choosing as reference the current situation. We considered the possibility that technology starts to be adopted in May 2003, and is completely established by December 2003.

From Table 5 we can deduce that all technological innovations considered cause an increase in the number of hives, relative to the RC. The major impact corresponds to the improvement of yield per hive. However, as shown in Table 5, only this improvement causes an increase in exportations, while with the other cases (decreasing mortality and costs) produces a fall in exportations. Again, this is due to an increasing number of active hives that depletes natural resources.

The effect of each technological change in comparison with the present conditions can be considered quantitatively. In Table 5 we show relative percentage variations, in 2006, for the number of beehives and amount of exported honey. In all cases the number of beehives increases. Nevertheless, the exports increase only when the yield increases, whereas it decreases with the beehive mortality and diminished costs.

6. Conclusions

We have developed a model for the honey agrifood chain that takes into consideration the essential aspects of the chain, reproducing with acceptable precision the real behavior from the initial situation in January 1991 to the first two months of 2002, considering the simplicity of the assumptions.

The quantitative analysis of diverse future scenarios has a limited validity, due to the present changes in the economic situation of the country. The peso devaluation has a great effect in the dynamics of the model, which generates an important increase in the number of productive hives, impelled by the exports. This effect hides the other analyzed scenarios, which have relative less impact, being of significance only the results that are derived from the comparison with the established reference case.

The constructed model can be improved in several aspects that would increase significantly its performance. As examples of this we can mention a detailed analysis of the production separated in regions, and the cost structure as well.

In the first case, it is possible to improve the production parameters, that in our model only appear as average values, besides having a great dispersion (for example, the yield or the climate). The inclusion of detailed cost information and the structure of certain chain agents would allow to obtain a complete analysis of the economic sector dynamics.

The improvement of the correction factor of beehive's yield (assumption #4) and the inclusion of other secondary commercialization channels (for example: Producer ➛ Exporter) into the model would give a more realistic and precise picture of the chain.

Although its good current global positioning as national exporting business, reengineering is needed in Argentinean honey chain to better cope with the expected changes. Finding better tools for forecasting future demand, measurements of chain performance (for instance, when modeling price paid to primary producers) and how to better allocate resources are desirable objectives. For these purposes, SD has proved to be an useful tool for predicting future scenarios in not only in honey chain but in other agrifood chains, on the basis of the set assumptions of the model developed.

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