Effects of Food Availability Policies on National Food Security: Colombian case

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Abstract—Food insecurity is a problem that affects population worldwide, mainly in developing countries. Due to the multiple interactions, the process of decision making to tackle this problem is becoming increasingly complex. This research explores the food availability system of a country, as a constraint to meet the basic food needs. Through System Dynamics, it is possible to understand its structure and effects of policies to help alleviate the problem.

Keywords—Food availability, food needs, food security, politics, production factors.

1. INTRODUCTION

For the past four decades the entire world and specially developing countries, have focused their attention on the high proportion of those affected by famine and undernourishment. According to the latest report published by the Food and Agriculture Organization of the United Nations (FAO) more than 1,020 million people lack Food Security (FS) (FAO 2009b), and in Colombia more than 6 million (NU 2009; ICBF 2006); this estimate has been increasing considerably since 1995-97. Yet the 1980's and early 1990s, showed a significant progress in reducing hunger, though slower than the necessary to meet hunger-reduction as proposed by the first Millennium Development Goal.

The definition of FS adopted in this research is the one proposed by FAO (1996), which states: "*Food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their food needs and preferences for food, in order to achieve a healthy and active life*". Stages to accomplish FS are hierarchical in nature, that is, adequate amounts of food might be produced, but may not be accessible by the hungry due to price, distribution, income limitations or cultural factors. Similarly, access to food might be necessary but not sufficient to ensure appropriate use, for this requires a safe and proper food preparation, as well as quality of nutritional diets (Barrett 2010; Pinstrup and Herforth 2008). Additionally, stability on FS has implications in all its dimensions (FAO 2009; 1996) that brings forth changes in inventories or cyclical events (Richardson 2010).

Meanwhile, the availability of food faces major challenges since the world needs not only to increase food production for a growing population (Latham 2000), but to use different raw materials for agro-industries. Increased food consumption puts pressure on limited natural resources to meet basic needs (Gerbens et al. 2010), as arable land and water (FAO 2003; Hoekstra and Chapagain 2007; WWF 2007), being this a major cause of both depletion of resources and emissions of greenhouse gases (Carlsson et al. 2005; Kramer 2000).

Agriculture in itself, and productive systems, are the basis for food production, so they provide the necessary components to maintain a healthy and active life such as water and the three macronutrients: Carbohydrates, fats, and proteins (FAO 2010; Thomson and Metz 1999; Whitney and Rolfes 1999; Rose 1999). Existing research on agriculture and FS often target trends over time, emphasizing the need to increase agricultural production (Gerbens et al. 2010).

The food availability subsystem is identified as a key one to ensure FS to a population. One of the issues we wish to study in this research is related to the capacity of land to produce enough food for a growing demand and meet minimum nutritional requirements of a population. Hence, we developed a System Dynamics simulation model, to better understand the phenomenon and carry out policy analysis. Whereby features related to factors of production and productivity are taken into account.

Section 2 of this article shows the current status of food availability in Colombia and issues that affect current food availability. Section 3 presents an approach to the model and describes the methodological requirements and modeling assumptions. Section 4 brings in previous results and Section 5 present conclusions and future research.

2. WHAT ARE THE ISSUES THAT AFFECT FOOD AVAILABILITY IN COLOMBIA?

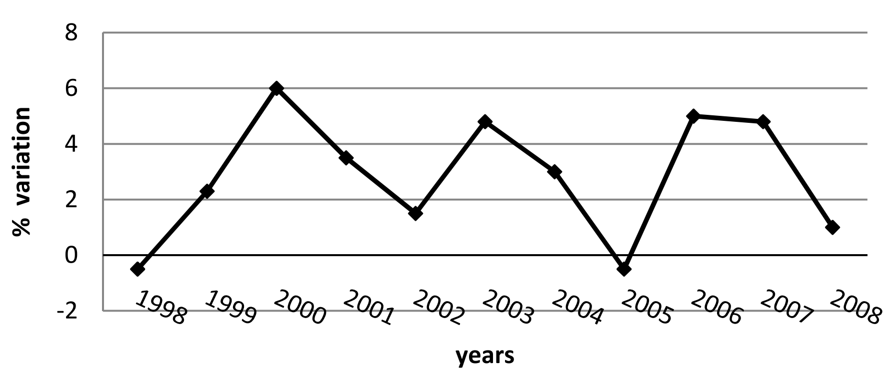
Food availability has several direct effects on the FS of a country. The first impact counts for the adequate and available provision to meet domestic food demand for both food and non food industry in the country. The second, counts for changes in certain transitory group of products, which are contained in *pancoger* products and have implications on the economic conditions of the most vulnerable population, since these constitute their livelihood (FAO 2009a).

According to a National Survey on the nutritional situation in Colombia (ENSIN), the prevalence of food insecurity in Colombia is about 40.8% of households (ICBF 2006). This prevalence is with no deviation related to two direct causes: the instability of basic food supply and limited access to basic foods.

2.1 Recent food patterns in Colombia

In analyzing the behavior of domestic food availability, there is a marked fluctuation in food supply, measured in terms of volumes of production plus imports. Figure 1 shows fluctuations in food supply in Colombia between 1998-2008.

Figure 1. Fluctuation in Colombia food supply



Source: Ministerio de Agricultura y Desarrollo Rural (2009)

At the aggregate level, the availability of food in Colombia has a good degree of sufficiency, except for cereals, since domestic consumption is greater than what is produced. In per capita terms, food consumption has been increasing substantially over the past ten years, from 1.6 kg/day in 1999 to 2.0 kg/day in 2008. As shown in Table 1, between 2002 and 2008, the increase in Colombian imports was 33%, from 6 million tons in 2002 to 7.9 million in 2008, as production grew by less than domestic consumption, that is 15% against 33%, respectively.

Table 1. National food balance

National total (Million ton)	2002	2003	2004	2005	2006	2007	2008
Production	24.8	26.5	27.2	26.4	27.1	28.2	28.6
Imports	6	5.7	6	6.2	7.5	7.9	7.9
Exports	4.1	4.3	4.5	4.6	4.3	4.3	4.1
Apparent consumption	26.7	27.9	28.7	28	30.3	31.8	32.4
Self-sufficiency	93%	95%	95%	94%	89%	89%	88%

Source: Ministerio de Agricultura y Desarrollo Rural – Dirección de Política Sectorial (2009)

Increased imports from Colombia have been due to the group of cereals, mainly wheat and maize, from 3.6 million ton to 5.2 million between 2002 and 2008. Out of the agricultural imports in 2002, these volumes represented the 60%, increased by 6 percentage points in 2008 that is 66%. The increment in imports of cereals is basically due to: 1. The demand for yellow corn for the feed industry and 2. The demand for wheat in the baking industry, as the country has no suitable growing conditions for such a product.

2.2 Limitations in the food production factors

As a result of a gradual population growth, the increased demand for goods and services puts pressure on natural resources and caused long term qualitative and quantitative changes. Food availability is associated primarily to two factors: production volumes and prices; they have a great influence over planting customs of producers. The main causes associated with instability on food supply are the limited access and inappropriate use of land factor.

2.2.1 Access to production factors

Colombia's agricultural sector has been characterized by a historical not equitable distribution of land among small farmers, many are located in areas with low soil quality. According to Instituto Geográfico Agustín Codazzi (IGAC), 3.4% of total national landowners concentrate 67% of the total rural area and 64% of producers own less than 3 ha.

In regard of water resources, Colombia has 6.6 million ha of irrigable land, of which only 13% have improved irrigation and drainage (Banco Mundial 2003). On the other hand, agricultural loans has shown a 403% increase, from 27.371 loans granted in 2002 to 137.826 in 2008 (FINAGRO 2009). Finally, technical assistance services are a key determinant for productive development of agriculture. According to Encuesta Nacional Agropecuaria (ENA), in 2006 only 8% of the production units used technical assistance services, showing also the low use of seeds and reproductive quality material (MADR & CCI 2009).

2.2.2 Inappropriate use of land factor

The sufficient food production to meet the demands of a country is closely related to the uses given to land resources and their potential usage. Classifying the potential use of land in Colombia has made possible to equate results within the vocation of Colombian soil. Table 2 shows the results of the last two classifications made by the IGAC (IGAC 1986; MADR & CCI 2009), obtained from the changes related to those areas suitable for cultivation and grazing.

Table 2. Potential land use in Colombia

Activity	Potential million ha (1985)	%	Potential million ha (2001)	%
Crops	14,0	12,3	21,5	18,9
Grazing	19,2	16,8	14,2	12,5
Forest	78,3	68,6	71,2	62,5
Water and urban	2,3	2,4	7,0	6,1
TOTAL	**113,8**	**100**	**113,9**	**100,0**

Source: (MADR & CCI 2009)

In summary the ENA concluded that the use of land within agricultural boundaries is characterized by the presence of inconsistencies between the classification and the vocation of the land, that generates physical and socioeconomic land use conflicts, related mainly by the inequitable and concentrated tenure of land. Although Colombia has 21 million ha of agricultural potential, only 4 million are cultivated, while livestock takes 42 million ha but only 14 million are suitable for it (DNP 2005).

2.3 Internal conflicts in food distribution

One of the factors influencing the distribution of food refers to the topography, hindering access to certain regions. Distribution from production areas to consumption centers is directly related to road conditions, infrastructure, and fluctuations in domestic fuel prices, which depend heavily on international rates.

Problems related to road infrastructure lead to the delay in coverage and quality of the country's road network. According to the Banco de la República, Colombia has a limited road network and limited capacity compared to other Latin American developing countries (Pérez 2005). As for the quality of the roads, the Ministry of Transport states that in 2004 the total of national paved routes in good condition, reached only 59% (Ministerio de Transporte 2008). Given this, and taking into account that in Colombia, approximately 80% of the total load is transported by land; the effects represent overruns for the economy and for the consumer.

Another important issue is related to prices-since these depend largely on internal and external factors- affecting both production and the economy. Likewise food price inflation, results from the increased demand for food against the proportion on supply due to changes in food preferences and increasing income as has been proved in global prices of cereals that in overall fluctuate at about 50% in real terms over the past 35 years (Brown 2009). This situation directly affects both: the poorest´s income and their effective demand for food.

2.4 Effects of environmental degradation and climatic factors

Natural resources determine the provision of food, income and employment -that are the basis of livelihood- for the vulnerable population living in rural areas. Land degradation, loss of water and crops, contribute to malnutrition and health problems. Under these given circumstances, improving local environmental conditions may reduce the vulnerability of the poor and may generate more possibilities and opportunities to improve the living standards of the population.

According to the National Planning Department, the production model prevailing in the country, is characterized by misuse of compound fertilizers, pesticides, fungicides and herbicides (DNP 2005), hence bringing in problems to the environment and to the agricultural sector; as an evidence, the area under cultivation has dropped by nearly one-fifth (MADR 2005) implying an increase in the intensity of land use and productivity growth that is nowadays practically unsustainable.

3. APPROACH TO THE MODEL

A System Dynamics (SD) model has been designed in order to extract knowledge about the dynamics present in food availability, to identify leverage points, and evaluate potential policies that generate stability and sustainability within the system.

3.1 Methodological requirements

Given the characteristics of the phenomenon, we propose the use SD as a causal-descriptive methodology. This method is a complementary tool for the study (Saeed 1994; Giraldo et al. 2010). The DS deals efficiently with problems at a high level of abstraction, and focuses on macro and strategic levels (population dynamics, sectorial studies, ecosystems, etc.) (Sterman 1988; Saeed 1987; Meadows et al. 1972). It conducts the study of the behavior of complex causal systems, and addresses research questions related to the knowledge on the when and how small events cause major disasters.

Generally, models developed for FS use econometric tools as a means to project or predict short and medium term policies (Giraldo et al. 2010). In sum, the DS is a complementary method to address such a problem because:

- It is a methodology to analyze dynamic systems, on a continuum, and it is also conducive for modeling and simulating complex systems.
- It gives insight into the structural causes that explain the behavior of the system and each of its parts. It is precisely this property what makes this approach so appropriate to simulate actions on the system and evaluate predicted performance over time.
- Allows to identify critical variables that affect the phenomenon; how they behave and face induced changes by promoting the development of potential scenarios.

It has features such as friendliness, transparency, guidance for policy development and capacity of comprehensiveness.

3.2 Model assumptions

Hereby some of the scope and assumptions of the proposed model:

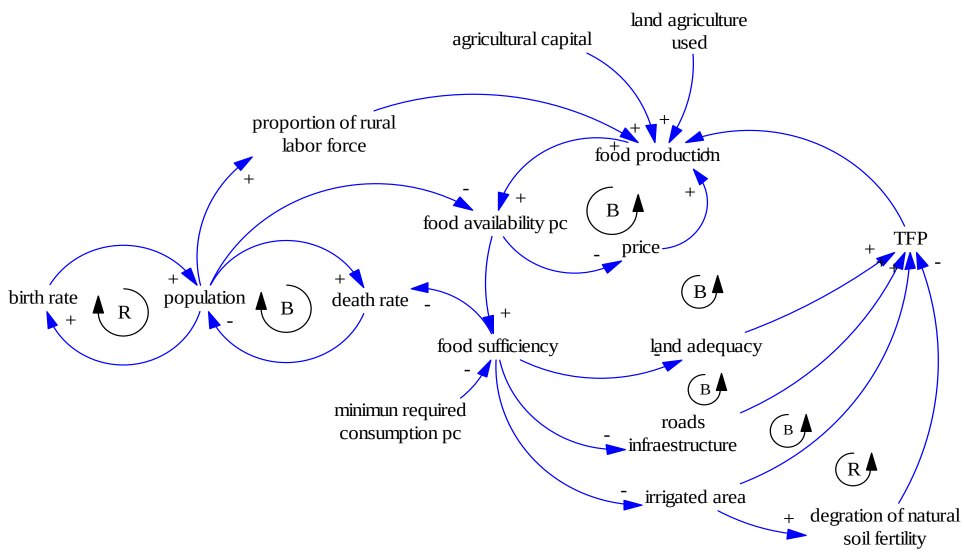
- It makes no distinction among agricultural products, as it aggregates the output in terms of equivalent kilograms (according to the caloric value of each subgroup).
- It assumes that food production must meet the internal needs of the country. If required, food will be imported, but if there exists some surplus, then it will be exported.
- Other uses of agricultural products are considered exogenous in the model.

- The model uses Vensim as simulation tool, using a time horizon of 30 years and annual simulation step.

3.3 Food Availability from the systemic perspective

Food availability and FS are dynamically related, which is represented in our dynamic hypothesis for system behavior. Figure 2 shows the relationship between the main variables of the model. The figure shows an interaction between the following major components: 1) Food sufficiency, 2) Food production, 3) Basic needs, and 4) Total factor productivity (TFP).

Figure 2. Causal loop diagram of food availability



One of the major pressures on the agricultural sector is to achieve enough food production for a growing population. Food sufficiency ratio is the best indicator of stock to feed the population, and is a function of both: Food availability and food consumption required (Bach & Saeed 1992) that is considered as adequate to carry out an active and healthy life. Food sufficiency is affected by population growth, and negatively affects life by increasing the rate of mortality.

When the amount of available food that is, the food domestically produced plus the stock inventories as well as the imported minus the exports- meets the needs of the population, it acts as a regulator of production, thereby impeding further production of food required. This behavior generates balancing loops as shown in Figure 2, regulating the production food system.

When food demand exceeds what the production system offers, there is real pressure on food production, generating a food gap. Generally, the strategies adopted to meet these food gap are framed into rapid and cheap methods (Bach & Saeed 1992), leading to a greater desired change in land use, and a consequent adequation of new land to be used in food production. According to Geist & Lambin (2001) and Stephenne & Lambin (2001), changes in land use is given by endogenous drivers such as land availability and accessibility, and other exogenous drivers such as the demand for commodities arising from national and international land policies.

The aggregate demand and food supply relationship directly affects the country's food supply and prompts favorable prices for domestic producers. These prices are of paramount importance in regard of the domestically amount of produced food and the quantity offered in the market to meet the food demands of households (Thomson & Metz 1999). Prices influence also the type of products to be cultivated and the overall level of productive factors such as land, labor and capital invested in agriculture.

Finally, industrial capital represents all physical means used for production: among others, machines and factories that produce manufactured goods, and supporting factors such as labor, land, and technology. The capital generates a continuous flow of production known as agri-food products, which is primarily the source of food for the population. Some of this agri-food production is allocated for final consumption in terms of food and raw materials for agri-industry. Another part of food production is aimed at generating more industrial capital through investments in the sector, which increases the stock of industrial capital that in turn will increment the production capacity in the future (Barney 2002).

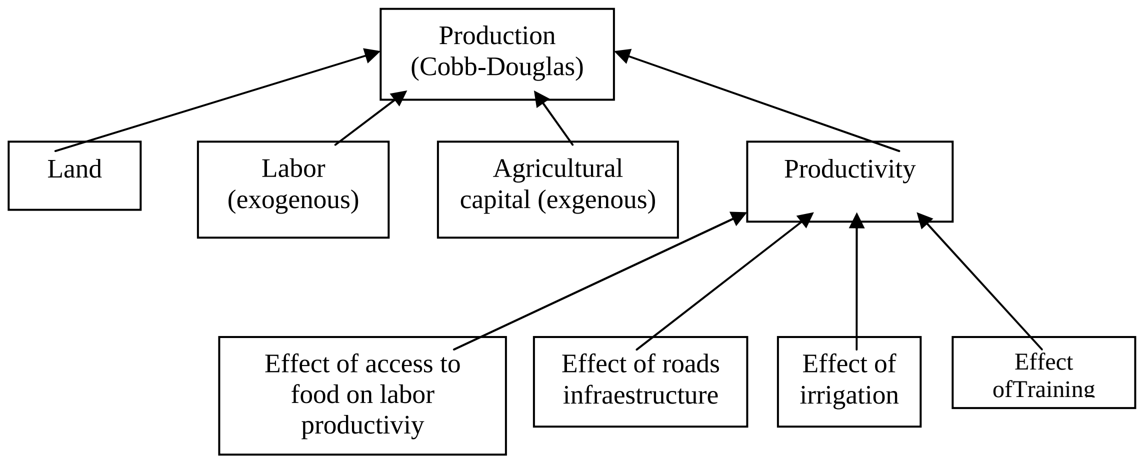
Food production, food sufficiency and total factor productivity (TFP) represents a negative feedback loop, but there exist different ways to improve productivity in food production given by the adequacy of land, development of road infrastructure, the average area irrigated, training rural labor force, and strategies for improving degraded soil.

3.4 Formal simulation model

In building models of SD it is common to distinguish between stock variables (or levels) and flow variables (or rates) (Sterman 2000). Stocks accumulate resource flows (or "activities") and represent the memory of the system. Stocks can be modified only by changes in the associated flows. The macrostructure of the model sketched in Figure 1 contains some stock variables: population *(N)*, agriculture products (*PA)*, food import (I_m), capital (*K*), roads infrastructure (*V*), potential land (T_p), used land (T_u) and degraded land (T_d). These are the state variables in our system. The level of each state variable is defined in terms of the associated flow variables (or "rates"). Stock and flow diagrams are given in Appendix 1. The main equations that describe the system are explained next.

The food production subsystem is similarly structured to other economic models in SD by the production function of Cobb-Douglas. The structure is shown in Figure 3.

Figure 3. Structure of food production



The function includes relationships between production factors: Land, Labor and Capital, and the Productivity. The total factor productivity (TFP) is endogenously developed, and relates outcomes such as road infrastructure, irrigation and drainage of cultivated areas, as well as technical training of farmers. Additionally it incorporates other effects related to performance in labor productivity due to access to food. The production function is represented by the function

$$Y = Y_0 * A * \left(\frac{T}{T_0}\right)^{\alpha} * \left(\frac{L}{L_0}\right)^{\beta} * \left(\frac{K}{K_0}\right)^{\gamma} \quad (1)$$

where Y is the amount of food produced, Y_0 represents the initial production, A is the total factor productivity, T is the land production factor, T_0 is the initial value of the land factor, L is the labor factor, L_0 is the initial value of the labor factor, K represents the capital, K_0 is the initial value of capital input. The parameters α, β and γ represent, respectively, the share of land, the share of labor and share of capital. These parameters help to measure how the food production responds to changes in factors of production.

The food import subsystem is incorporated into the model as a way of increasing the food supply. The import of food depends on a food gap; the difference between total food demand and availability of food products. When the demand for food is greater than the available food (food-gap), then two policies can be incorporated: a short term policy that relates immediately the food import requirement, and a long term policy, that relates the improvement of productive capacity or expansion of installed capacity through increasing land adequacy. The subsystem then is represented formally as follows

$$I_m = I_m(t_0) + \int_{t_0}^{t} [IH_{(s)} - IR_{(s)}] ds \quad (2)$$

$$IH_{(s)} = \frac{B_r * PI_H}{t_I},\ IR_{(s)} = I_m \quad (3)$$

$$PI_H = Ci_{IB} * PR_I^{\,e_{IP}} \quad (4)$$

$$B_r = MAX(D_T - DA_g, 0) \quad (5)$$

where I_m represents food imports, and is based on IH_s, IR_s y $I_m(t_0)$ that represent both: pending imports, real imports and the initial value of imports over time t_0 respectively. $IH_{(s)}$ is the pending rate of imports, and behaves as a first order exponential delay and is given by the B_r food gap, and the percentage of pending imports PI_H as well as the time adjustment of imports t_I. For model stability purposes, the output rate $IR_{(s)}$ is equal to the accumulated value at the level of food imports I_m. The percentage of pending imports is defined as a function in terms of the initial coverage of imports into the food gap Ci_{IB}, the relative prices of food imports PR_I and elasticity of imports to food prices e_{IP}. Finally the food gap B_r is defined as a MAX function that lays between total food demand D_T and the availability of food products DA_g.

The price of food imports has been defined as a weighted average among the commodities that provide the greatest proportion of food imports. As described in Section 2 the cereals, specifically corn, wheat and soybeans, constitute about 93% of imports in the sector. According to the ENSIN, these products are part of the basic food group, contributing significantly to the daily calorie intake per person. To define import prices, the price of each commodity was considered to the year base and its participation within the cereals (FENALCE 2010).

Accordingly, food sufficiency is represented as an auxiliary variable, which relates the difference between food availability and the minimum requirement of consumption per capita. In turn, the availability of food is calculated by adding the existing products in agriculture. On the other hand, the minimum required consumption is defined as a normative basket of 2519 cal/day (Trumbo et al. 2002). To obtain an equivalent in terms of quantities produced and energy requirements; there has been a conversion of food products in grain equivalent, based on calorie content (USDA 2005). The food sufficiency subsystem is given by

$$DA_g = PA(1 - PNA) + I_m \quad (6)$$

$$FA_{pc} = \frac{DA_g(1 - DO_u)}{N} \quad (7)$$

$$PSA = \frac{(FA_{pc} - CMR)}{CMR} \quad (8)$$

where DA_g represents the availability of food products, and is a function of PA, PNA and I_m that represent agriculture products, the percentage of non-food products and imports, respectively. In this way, the food that is available for consumption and nonfood uses is obtained. FA_{pc} represents the available food per capita, which is based on the availability of food products DA_g, the demands for non food uses DO_u and the population N. Basically, the ratio of food sufficient PSA is represented in terms of availability of food per capita FA_{pc} and the minimum consumption required CMR. The food sufficiency variable entails that if it is greater than or equal to 1, there is enough food to meet the minimum requirements, but if it is lower than 1, indicates scarcity of food.

The land subsystem, is represented in the model by two structures, that differentiate agricultural land from the land used for livestock. Such a distinction was necessary due to conflicts in the use and vocation of land in Colombia, given by a high component of underutilization. Meanwhile, the land used for agriculture is integrated by a system that involves the potential land use, used agriculture land, and subsequently, the land that suffers degradation (Oldeman et al. 1990). The desired change in land use, is marked primarily by the food gap, food prices and state policies (Geist & Lambin 2001), (Stephenne & Lambin 2001). The subsystem of land is represented as follows:

$$Tp_a = \int_{t_0}^{t} [Cpa_{(s)} + tr_{(s)} - An_{(s)}] ds + Tp_a(t_0) \quad (9)$$

$$Tu_a = \int_{t_0}^{t} [An_{(s)} - td_{(s)}] ds + Tu_a(t_0) \quad (10)$$

$$Td_a = \int_{t_0}^{t} [td_{(s)} - tr_{(s)}] ds + Td_a(t_0) \quad (11)$$

$$A_n = {}^{MIN(C_d, Tp_a)}/_{tp_c}, \quad t_d = Tu_a * Fd_T, \quad (12)$$

$$t_r = {}^{Td_a}/_{t_g}$$

where Tp_a, Tu_a and Td_a are level variables that represent potentially arable land, used agricultural land and degraded land, respectively. Tp_a is given in terms of changes in land use from livestock to agricultural Cpa, regeneration rate tr, and the adequacy of new land An. Tu_a in turn, is represented by An and a degradation rate td. Finally, Td_a is given in terms of td and tr. On the other hand, the adequacy of new land A_n is represented as a function between the desired change in land use C_d and Tp_a. The adequacy is expressed as a first order delay due to an average time of land conversion tp_c. t_d, is reflected as a relationship between Tu_a and a fraction of land degradation Fd_T. Finally, the flow $\mathrm{t_r}$ is given as a first order delay between Td_a and the recovery of degraded land t_g.

4. Preliminary results

This section shows the preliminary results of the proposed simulation model, based on policies that affect food availability in a country, and thus the National Food Security. For the baseline scenario, the following decision rules are included in the model:

1. In the land production factor, the reference implies that land degradation is produced by a normal fraction plus the effect of degradation caused by irrigation practices.
2. The desired change in the use of land is a function of the food gap, the percentage of its adequacy and the food price.
3. The minimum required food is based on 2519 USDA cal/person- day as stated by the USDA (2005)
4. In the total demand for food, the minimum consumption required by population and the demand for other uses such as seeds, animal feeding, and processing, among others, have been considered.

Initially, the food gap is negative, because the quantity demanded of food is greater than the amount that is available, i.e., less than zero, then, a low level of food sufficiency is perceived as shown in Figure 4, leading to greater desired change in land utilization and hence the adequacy of new land.

A greater use of land factor increases food production as shown in figure 5. After the first 5 years of simulation, there will not be adequate land to be used in agriculture, however, during this time the current land in use suffers degradation as a result of different effects: The life average of the land and the effect of irrigation, hence the degraded land reduces its use in agriculture, as shown in Figure 6.

Figure 4. Simulation with the base line scenario of the food sufficiency

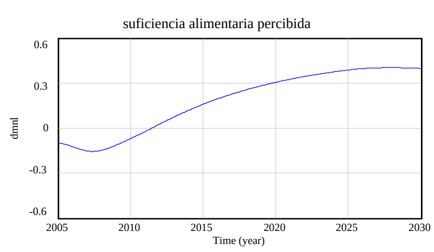


Figure 5. Simulation with the base line scenario of the agriculture production

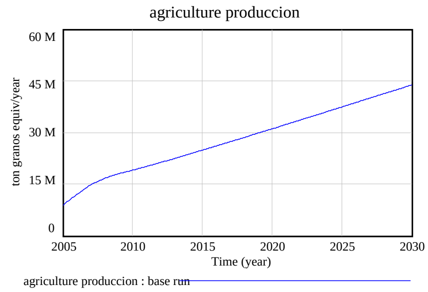


Figure 6. Simulation with the base line scenario of the used agriculture land

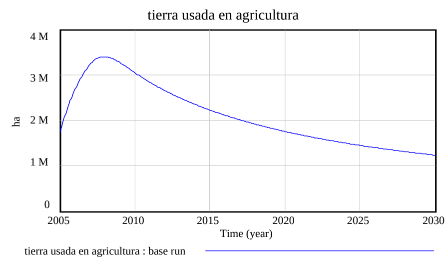
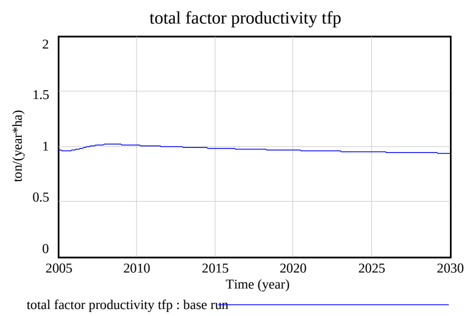
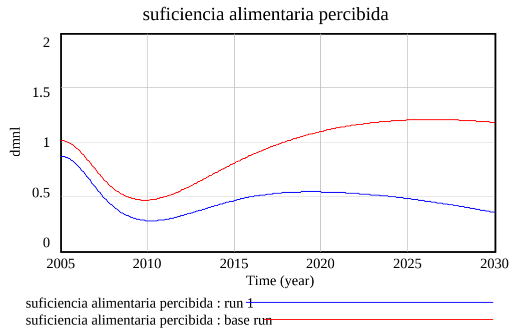


Figure 7. Simulation with the base line scenario of the total factor productivity



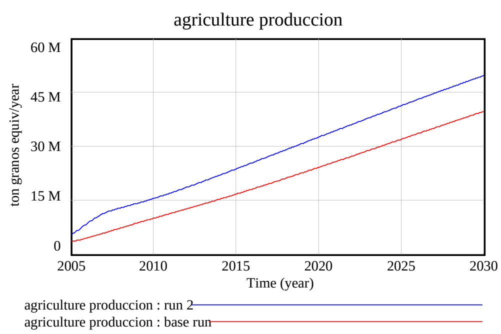
As possible scenarios that affect the proportion of food sufficiency are evaluated, it has been found that the total food demand increases by 10%; if the same proportions of production factors are used, and if the FTP continues the same, the FS of the country would be at further risk. Even if the behavior of the proportion of food sufficiency remains above zero -due to land degradation- the food production would decline, as shown in Figure 8.

Figura 8. Food sufficiency with increases in food demand by 10%



A sustainable way of increasing production would be through more efficient use of productive factors and productivity growth through: increasing producers training, increasing road infrastructure, major adjustments in irrigation and drainage; rather than the suitability of new land for agricultural use, as shown in figure 9.

Figure 9. Agriculture production with efficient use of productive factors



5. Conclusions

The strategy of adequacy of new land for food production, is not an appropriate decision in terms of sustainability, since the land suffer degradation over time due to both, the life average of the land and the effect of irrigation because off its use, affecting production food. Therefore, a way of responding to growing demands for food due to population increase, due to the use of raw materials for other industries is through increased productivity and efficient use of production factors. Taking into account the recent patterns in terms of food consumptions, the food security could be in risk, if the total factor productivity continues the same.

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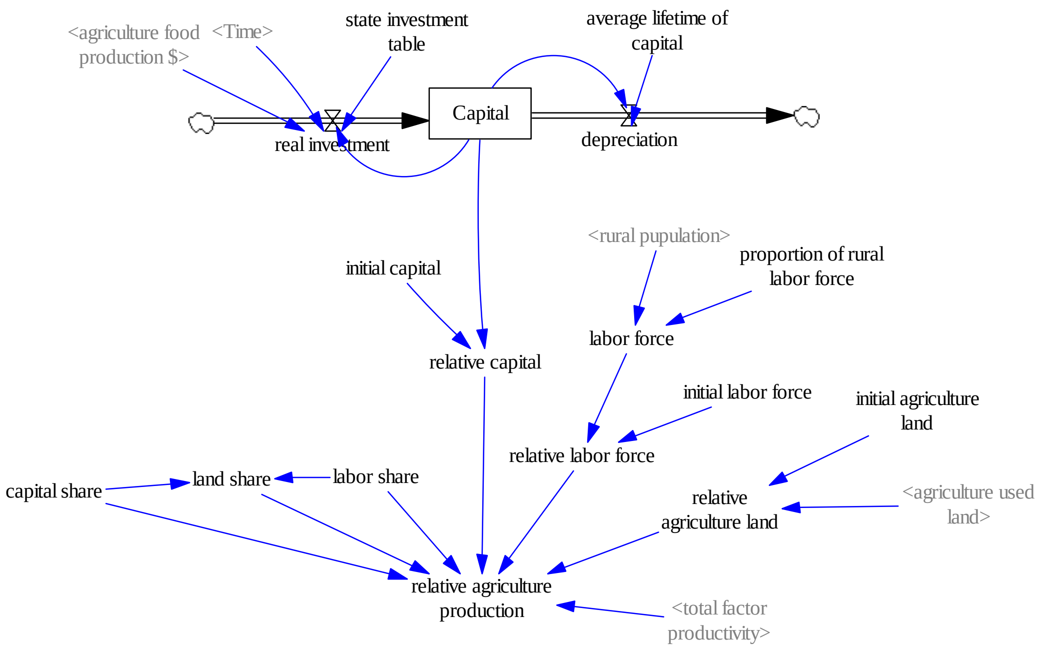
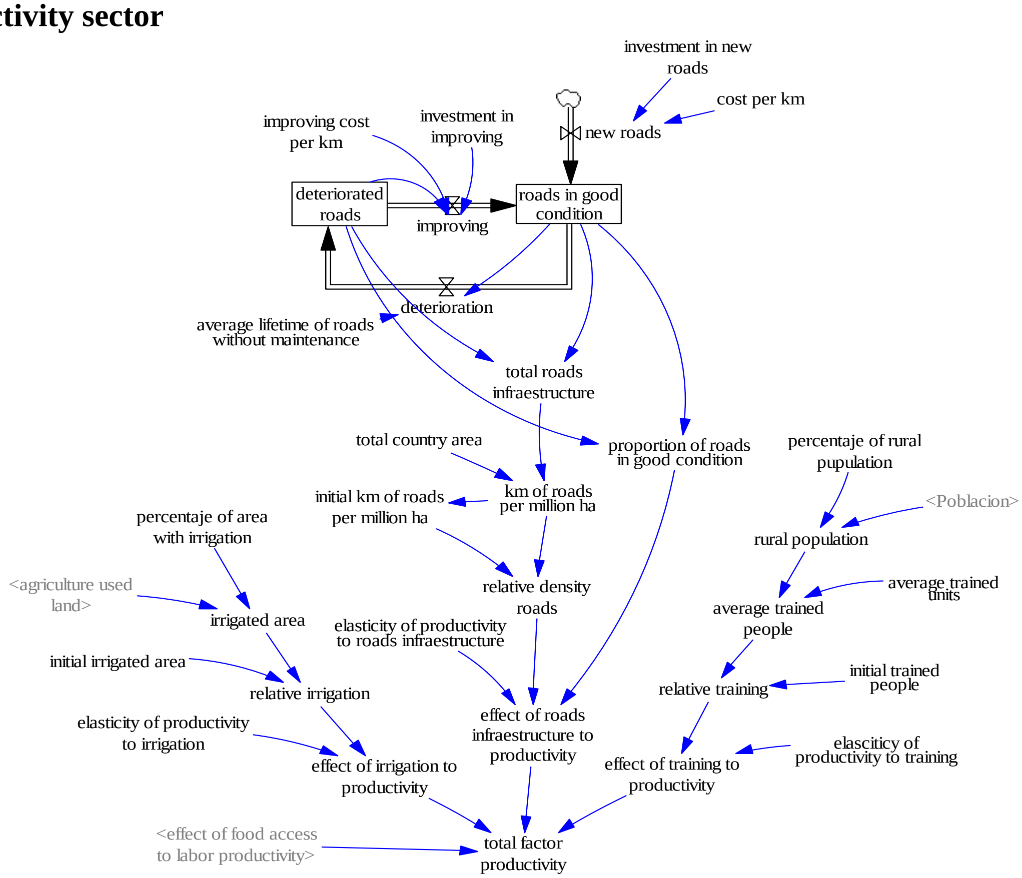
APPENDIX 1. Stock and flow diagrams

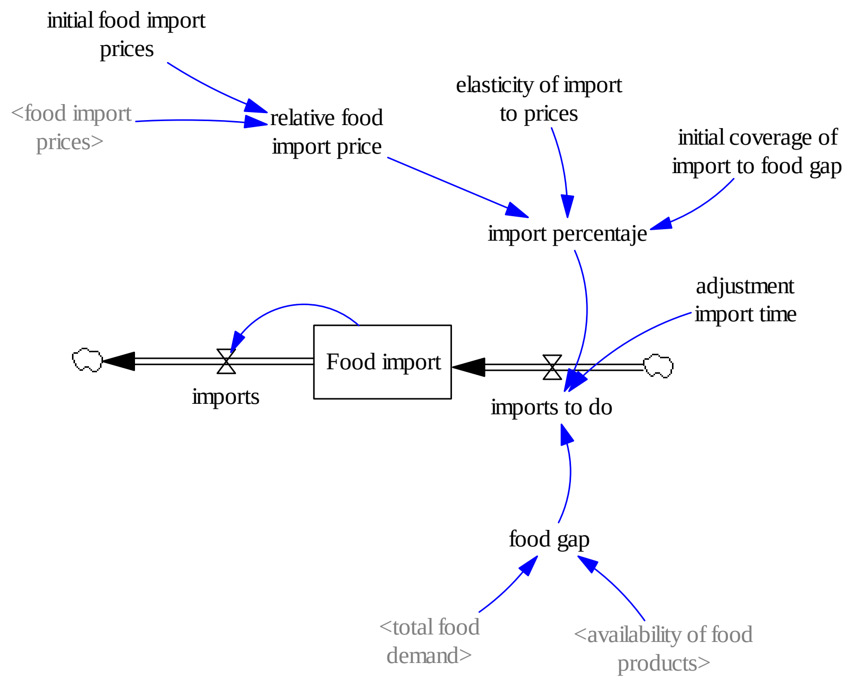
Production sector



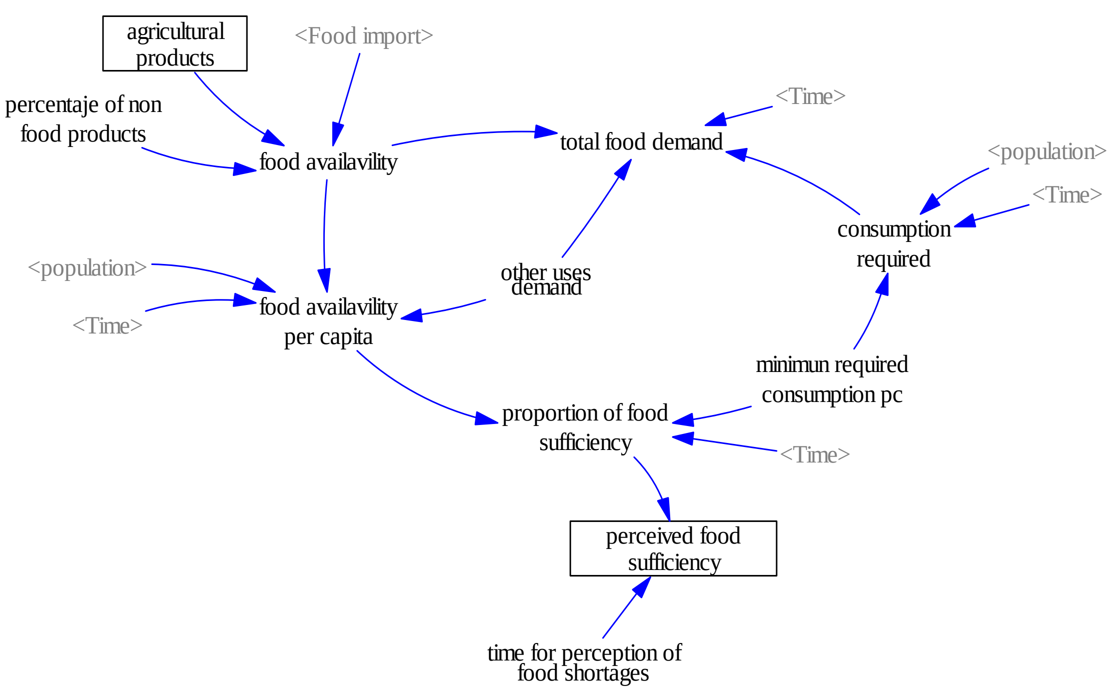
Productivity sector



Food import sector



Food sufficiency sector



Land use sector