Food Insecurity in Ethiopia: Population, Food Production and Market

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Abstract

This study investigates the underlying problems causing food insecurity in Ethiopia and tests, policy options that could alleviate the problem in the future. For this purpose, we designed, calibrated and tested a system dynamics model that integrates population, food production, and market dynamics. Model analyses show that in the past, both availability of and access to food constrained the actual food consumption of the population, that is both food supplies produced and purchasing power were insufficient for ensuring the required daily calorie intake of the population. Moreover, degraded land contributed considerably to the poor average productivity of the land. Policy analyses showed that future policy options such as land rehabilitation and capacity building for skilled use of agricultural inputs such as seeds and fertilizer need to be combined carefully to account for their different implementation times.

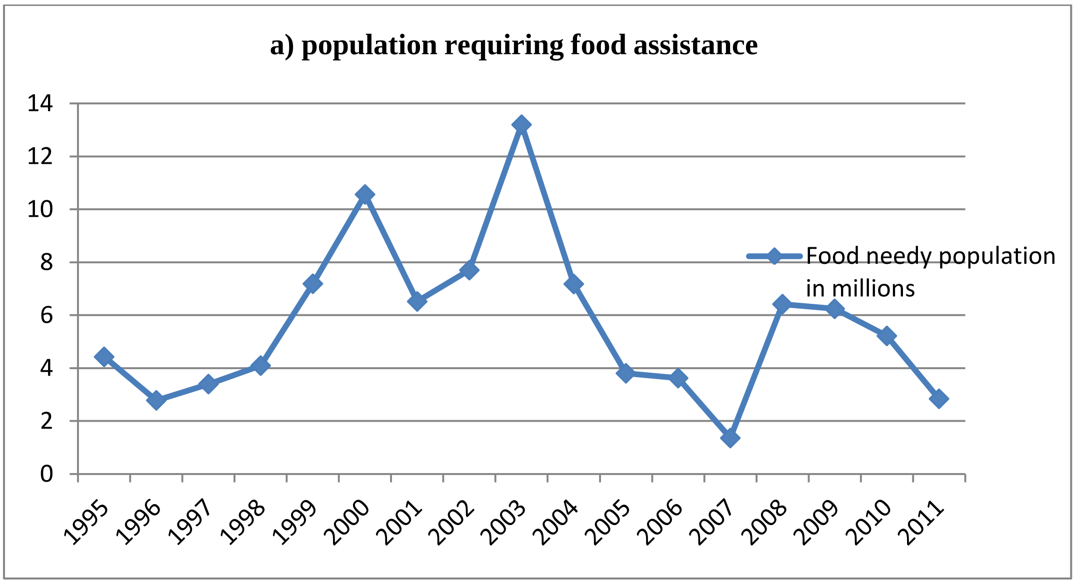
Key words: Food insecurity, system dynamics, land degradation, prevalence of undernourishment, food availability, food access, land productivity.

1. Introduction

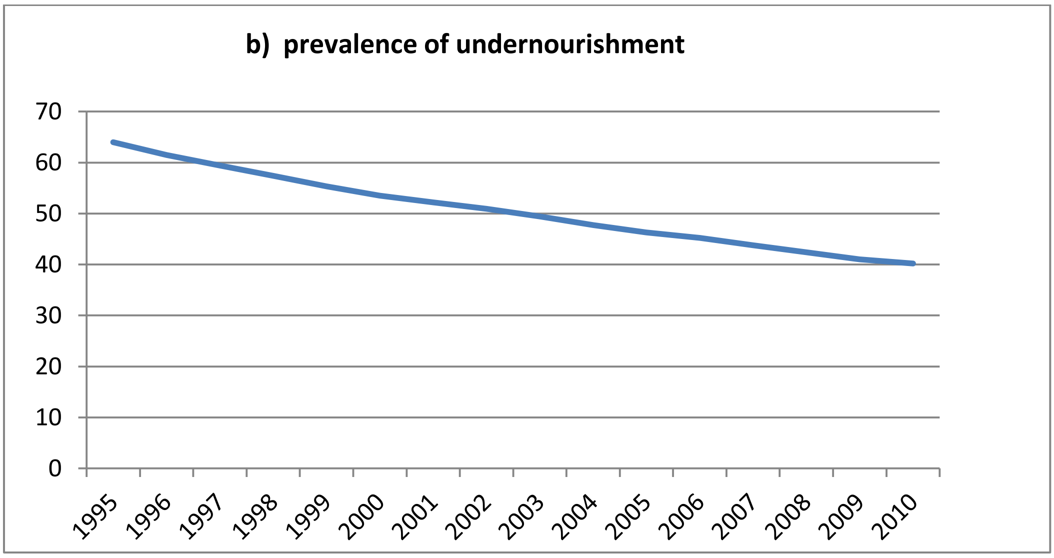
Ensuring food security remains a challenge in a world with a growing and more demanding population. Developing countries, such as Ethiopia, have been facing severe versions of this problem over long periods of time. The Millennium Development Goal on poverty and hunger aimed at reducing the number of undernourished people by 50 % until 2015, that is, to reduce it to no more than 420 million people in 2015. However, data showed that the number of undernourished people have increased to 1.02 billion worldwide in 2009 (FAO, 2009).

In Ethiopia, food insecurity has been a serious problem for decades. Since the 1970s, a series of production failures have resulted in chronic food insecurity (Kaluski et al., 2001). In the last few decades, several million people required immediate food assistance (figure 1a). As a result, Ethiopia has been the largest recipient of food aid in Sub-Saharan Africa. Another indicator to the extent of food insecurity at a national level is the prevalence of undernourishment. This indicator demonstrates that a large proportion of the population has been undernourished over the last one and half decades (figure 1b).

The proportion of population undernourished was 64 percent in 1995. Thereafter, improved progressively to 40 percent in 2010 (FAO-FSI, 2013). However, the prevalence of undernourishment still remains at such a high level that effort for future improvement is required.



Source: Disaster Risk Management and Food Security Sector (Figure 1a)



Source: FAO-food security indicators (Figure 1b)

From the total food production in Ethiopia, cereal constitutes the largest share. The increase in cereal production in the last decade has contributed to the decrease in the prevalence of undernourishment. The increase in the production however, does not decrease correspondingly the number of undernourished people since the population has been growing at the same time.

Agriculture is the main economic activity of many Ethiopians and the key characteristic of Ethiopian agriculture is its dependence on rainfall. The limited production and productivity has mainly been attributed to; insufficient and erratic rainfall, land degradation, low input application, rapid population growth and market imperfection (Chadhokar, 2003, Zelleke et al., 2010, Jolejole-Forman et al., 2012). Although, previous research has well identified the causes of food insecurity, little work has been done in integrating the various causes of food insecurity into one conceptual framework. In this paper, we use system dynamics, an integrated approach in model-based policy analysis and design to investigate the processes determining food insecurity and to examine the impact of different policies to alleviate food insecurity. For this purpose, we designed a computer simulation model that covers three sectors; population, food production, and market.

Our analysis addresses three of the four pillars of food security (FAO, 2003, FAO, 2006, Messerle, 2011) which are; food availability (presence of sufficient quantity and quality of food produced domestically, supplied from import or food aids), access to food (presence of sufficient resources to obtain appropriate food for nutritious diet), and stability (steadiness of both availability of food and access to food over times).

The simulation model reproduces well the historical time series variables such as population, prevalence of undernourishment, production, yields, and food/cereal price etc. Model simulations reveal that both availability of and access to food were important constraints to food security and that they are expected to prevail in the future. Future policy options such as land rehabilitation and capacity building for skilled use of agricultural inputs such as seeds and fertilizer need to be combined carefully to account for their different implementation times.

2. Driving Forces and Food System Activities Causing Food Insecurity

2.1 Population Growth

Rapid population growth has been regarded as one of the major causes of food insecurity in Ethiopia. The population has increased from 53.5 million in 1994, to 73.8 million in 2007 and it is estimated to reach over 84 million (CSA, 2011 DHS). Although, the population growth rate declined from 3.1 percent in 1984 to 2.9 and 2.6 percent in 1994 and 2007 respectively, this figure is sufficiently large to increase the population and put pressure for food production.

In spite of the fact that 80 percent of the population has been employed in food production, Ethiopia fails to feed relatively large proportion of population from its domestic production. And more importantly, the population do not have the productive capacity to earn wherewithal to commend its additional food requirements through commercial imports (Bikora, 2003).

Studies have also shown that the health problems of a large proportion of the population has emanated from lack of adequate and balanced diet. Malnourishment, which encompasses undernourishment, diminishes people's ability to work, care for themselves, and ultimately exposes them to disease. Children, pregnant and lactating women, and aged adults are the most vulnerable population to disease due to malnourishment (MH, 2003, Ali et al., 2011).

2.2 Drought

The main characteristic of Ethiopian agriculture is its dependence on rainfall. Annual and seasonal rainfall distribution is highly variable and droughts are frequent in some parts of the country which severely influences production (Ersado, 2005, Bewket, 2009). Rainfall is the ultimate source of water in that it is a resource for agricultural production. And also surface and ground water are feed by rain. Awlachew et al. (2010) estimated that Ethiopia receives about 980 billion cubic meters of rain per year. However, much of the rain water is lost due to the absence of adequate conservation and ineffective water harvesting activities. It was estimated that from about 110 billion cubic meters annual surface water supply, only one percent is used for irrigation and hydro power (Chadhokar, 2003).

2.3 Land Degradation and Fertility Decline

Degraded soil and degradation constitute a major constraining factor to agricultural production/productivity and contribute to the decrease in over-all agricultural production. Ethiopia in particular is vulnerable for soil degradation and has the highest rate of erosion (by rain water) in Africa (Jolejole-Forman et al., 2012, Zelleke et al., 2010, Sonneveld et al., 2002).

Numerous researchers have pointed out the various factors contributing to soil degradation in Ethiopia such as; soil erosion, complete removal of crop residues from farm land, use of animal manure as a source of fuel rather than source natural fertilizer, absence of appropriate soil and water conservation, deforestation, and population pressure (Zelleke et al., 2010, Amede et al., 2001, Jolejole-Forman et al., 2012, Keyzer et al., 2001). The use of animal dung and crop residues for energy instead of soil fertilization leads to the depletion of organic matters such as organic carbon and other nutrients like N, P, and K.

Most of the agricultural production takes place in the highlands (above 1500 m). This is where declining vegetative cover is very common. In three main forest regions of Ethiopia, 59,000 Ha forest per year has been converted in to agricultural areas (WBISP, 2004). The vulnerability of the land due to its topography (steep slope) together with poor cultivation practice causes soil losses to reach alarming level (Keyzer et al., 2001, Amede et al. 2001, Zelleke et al., 2010).

Estimates indicate that the annual loss of agricultural soil varies from 3.4-84.5 tones/ha/year (Sonneveld et al., 2002) and sometimes could be as high as 137 tones/ha/year or, in other words Ethiopia's top soil depth loss decreases by 4-10 mm each year (Sonneveld et al., 2002, Zelleke et al., 2010).

2.4 Market Imperfection

The market plays an important role in ensuring food security, if it is used efficiently in such a way that an optimal allocation of agricultural production originating from the place of production is transported to the place of consumption and if the market provides adequate incentives to the farmers to increase output. Demeke (2003) has identified the attributes of the Ethiopian food market as; inadequate market information system with a weak bargaining power of farmers, and undeveloped industrial processing sector. Also infrastructure, such as road transportation is commonly poor. An estimated 75% of the farmers are more than half a day's walk from an all-weather road (Demeke, 2003, Gabriel, 2003).

The market price of agricultural products is highly volatile. In the main harvesting season the price has been severely depressed to its lowest level because a large amount (around 79 %) of the annual production sale occur immediately after the harvesting season January to March (Demeke, 2003). When farmers are running out of stock, during the months of June to August, the price of agricultural production in general goes up. The volume offered at the cereal market drop sharply in the years of poor harvest causing the price to rise considerably. The seasonal fluctuation of price is estimated to discourage investment to maximize output. Surplus producing farmers would also be reluctant to make important investment in using inputs such as fertilizers and improved seeds in the presence of price instability.

Another issue, most importantly, is the vast majority of the population in the urban area earns very low income which influences the demand constraint of the food market. This pushes the price to a lower level. The combined effect of relatively small demand and low purchasing power of consumers in the food market has resulted in low price setting. Further the low food price of food products does not provide adequate incentives to the farmers to increase production (Demeke, 2003).

3. Model Description

Figure 2 provides an overview of the simulation model which has the three sectors population, food production and market. It illustrates the feedback loops linking processes within and across these sectors. A detailed description of the individual model sectors and their stock and flow structure is provided in the appendix.

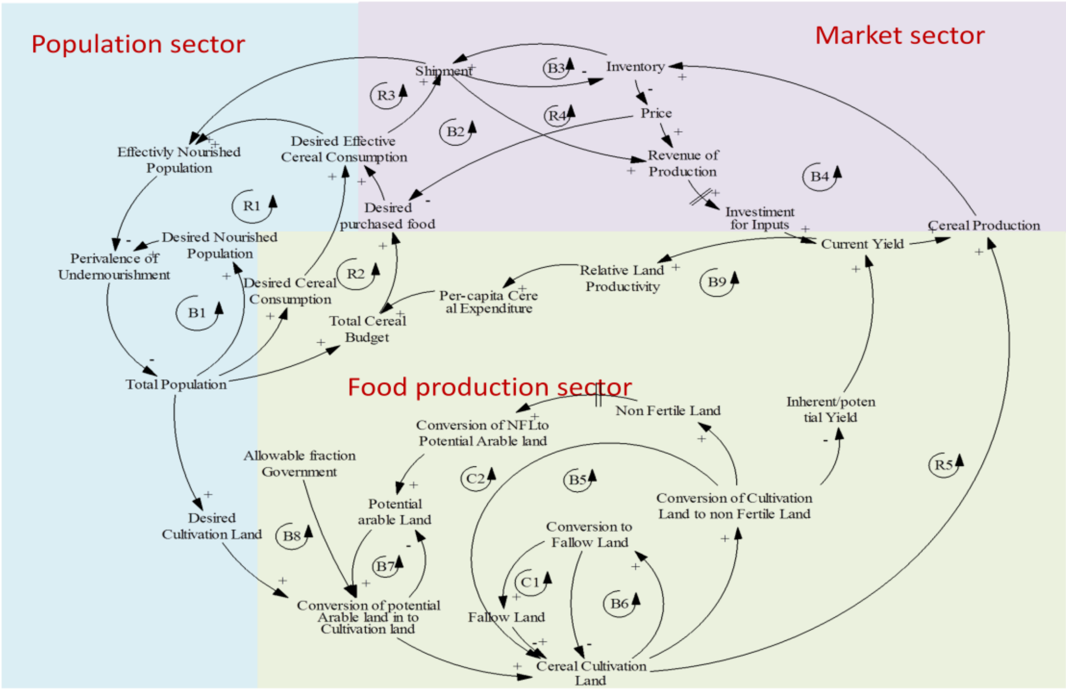


Figure 2*: Causal loop diagram representing the main feedbacks of the explanatory model.*

The prevalence of undernourishment is one of the main food insecurity indicators which represents the proportion of the total population that is undernourished (people who receive an amount of food whose calorie content is continuously below the minimum daily calorie requirement). The tighter the constraining factors, access to or/and availability of food, the lower is the food consumption. Low food consumption, subsequently results in high prevalence of undernourishment. The undernourishment, however, causes an improper functioning of the body, diseases, and premature deaths (or low life expectancy) which over time decreases the population (loop **B1**).

The growing population has been causing the food demand to increase. Therefore, both growing food supply (physical access or availability) and the potential to access the food (purchasing power) has been required to keep the momentum. However, the availability of and access to food has been governed by different mechanisms. As a result, both availability of food and access to food at times have been contributing to the limited food consumption (loop **R1**).

The availability of and the access to food are equally important to the population at household level in determining the actual food consumption. In other words, both the purchasing power (economic access) and the actual food supplies have been the main cause for the high percentage of undernourished people. The larger the purchasing power, the larger would be the amount of food purchased (if available) for consumption. This would imply relatively small numbers of people would be undernourished causing to increase the population. Similarly the larger the amount of food available in the market, the larger would be the amount of food purchased and would result in smaller number of people undernourished (loops **R2**, and **R3**). Whereas **R2** constrain actual food consumption by limiting purchasing power, **R3** constrain actual food consumption by limiting food supply.

The desired food consumption, materialized in the purchasing power, called the food demand, is one of the main constraints of actual food consumption. This means that, all the desired food consumption which is based on the minimum calorie requirement has actually not been acquired for consumption. Rather, only a part of desired food consumption which is accessed upon the presence of purchasing power and availability of food in the market, is used for consumption. The food demand is based upon the average per-capita food budget compared to the current price of food. Hence the price of food has a significant effect on the desired purchased food/food demand, and shipment. A high food price causes to decrease the amount of shipment and reduce the amount of food to be accessed, subsequently results in relatively high percentage of undernourishment (loop **B2**).

The inventory is mainly filled by the Meher and Belg cereal production. If there is no sufficient production delivery that substitutes shipment for consumption, then the inventory will be depleted. This influences back shipment, and food price resulting in limited consumption. The increase in inventory causes an increase in shipment. But, as the shipment depletes the inventory, the increase in shipment, over time, causes a decrease in the inventory (loop **B3**).

The growing population demands an increasing supply of food from domestic production mainly from Meher/main season production. As a result, the supply of food must increase through either the intensification of cultivation land or the increase of land productivity (loops **R4** and **R5**). Hence, both the cultivation land and the yields of cereals have increased significantly since early 2000. However, the increase in the cultivation land has been practiced through the depletion of the natural resources such as forest and grazing land (loop **B7**). The existence of poor land management practice along with soil erosion gradually causes the cultivation land to lose its topsoil which subsequently results in decrease in water retaining capacity, and decrease in productivity. And after a long time, the cultivation land transfer into non-fertile land (loop **C2**). Hence, the increase in cultivation land with the presence of poor soil management results in an increase in the conversion of the fertile land into non-fertile land. The non-fertile land requires a considerable amount of time to return to a fertile state. The mechanism that farmers use to slow down land productivity caused by the soil erosion is through temporarily fallowing. The land fallowed for some time (maximum of five years) so it recover its productivity (loop **C1**).

While the land became non-fertile by soil erosion, it passed through various stages of degradation and its productivity decrease successively (**B5**). On the other hand, the revenue of farmers can be increased in two ways, (a) resulting from the increase in producer price (which is governed by **B4**) or (b) resulting from the increase in sell shipments provided that they produce a sufficient amount (governed by **R4**). The increase in price causes an increase in revenue, and then, increase investment for agricultural input. In the presence of inherent / potential yield of the land, the increased investment in agricultural input causes an increase in current yield. The increase in current yield (multiplied by the existing cultivation land) causes an increase in the cereal delivery and, consequently the inventory. But the increase in inventory has two effects; (a) it causes the price to diminish which results in a decrease in revenue, and (b) causes an increase in shipment which causes revenue to increase.

Farmers consume a large share of their production. The increase in productivity of the land creates more availability of and access to food for the farmers themselves. This considerably contributes to the increase in per-capita food consumption. Hence, the increase in land productivity improves (decreases) the prevalence of undernourishment by increasing food consumption (loop **B9**).

4. Model Calibration and Validation

4.1 Data

Data is important for computer based modeling and simulation analyses. We used data for estimating model parameters, initializing stock variables, describing exogenous variables and comparing real behavior (time series data) with model output. Socio-economical and Environmental data are utilized from local sources such as CSA and EMA and international sources such as FAO and WB. Furthermore, data from reports, publications and interview of field specialists are used for estimating some parameters in the model.

4.2 Model Validation

Models are useful tools if they generate the right behavior for the right reasons. The purpose of model validation is to build confidence in the usefulness of the model for the intended purpose. The causal structure (figure 2) stands for the causal hypothesis describing the interaction of causal relationships of the factors over time. Therefore, the validity of this model mainly depends on the validity of its structure rather than the statistical fit between the model output and data (Barlas, 1994, Sterman, 2000). Several model validation testes such as unit consistency test, comparison of reference and model simulated behavior test, structure-behavior test, extreme condition test etc. are made to build confidence on the usefulness of the model. Of these validation tests, two of them are presented below.

4.2.1 Reference and Model Simulated Behavior

This section compares the model results with time series data. The comparison of the simulated model behavior with the historic data helps us to examine whether the simulation model has explained sufficiently well the behavior of the actual data. Figure 3 (a-f), are some of the comparisons between the data and model simulation behaviors from the three sectors. The coefficient of determination

(R^2) is close to one for most of the variables which means the model explains important fraction of the variance in the data. The R^2 for population, prevalence of undernourishment, yield, cultivated land and producer price are 0.99, 0.86, 0.74, 0.81, and 0.96 respectively.

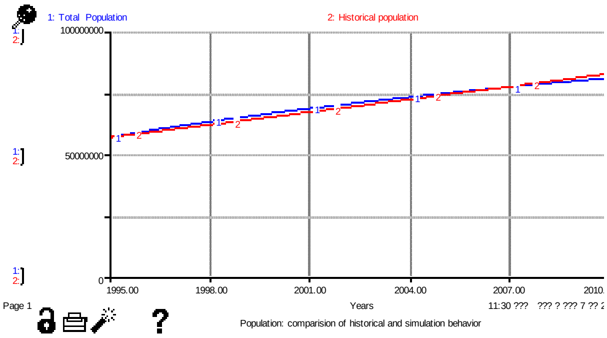


Figure 3 (a): Total population

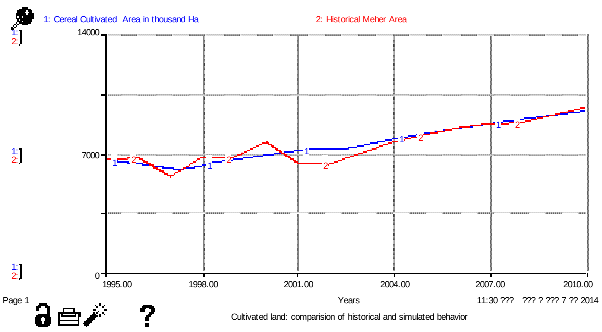


Figure 3 (b): Cultivated land

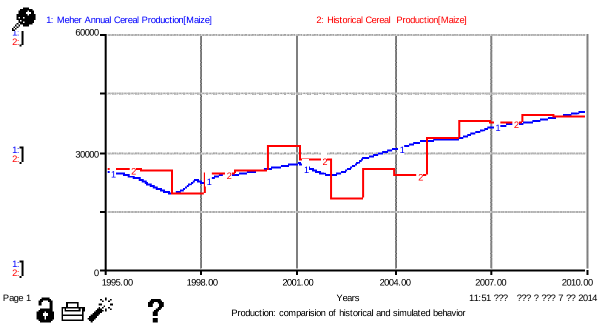


Figure 3 (c): Maize production

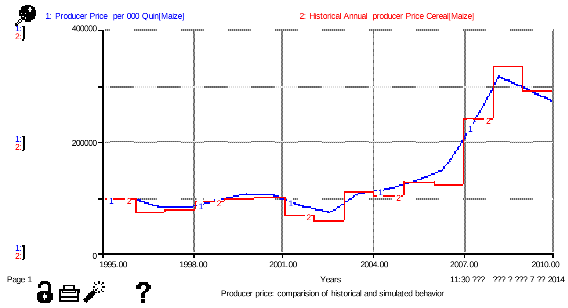


Figure 3(e): Producer price, maize

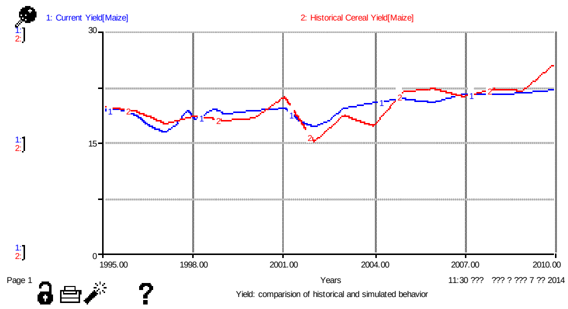


Figure 3 (d): Maize yield

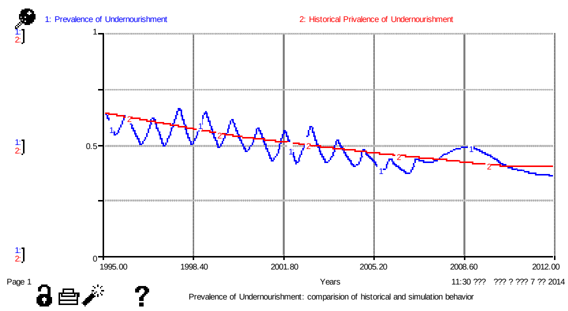


Figure 3 (f): Prevalence of undernourishment

Figure 3(a-f): The comparison of historical (red) and model simulation (blue) graphs.

4.2.2 Structure-Behavior Test

Structure-behavior test aims at assessing the validity of the structure indirectly by applying some behavioral test. In this section we examine the relationship between the model structure and its simulation behavior when some loops are cut (become inactive). We test whether the cutting of the loops; **R2**, **R3**, and **B5** (figure 2 above) have the same real implication with the simulation behavior of the model.

We call the model result before the loop is cut, the structure that replicates the reference behavior, as the business as usual (BAU) ran. And then, we compare it with the model result after the loop is cut. The dynamics of the food demand of the population is governed by the reinforcing loop, **R2**. That is, the loop **R2** computes the amount of cereals needed for consumption from the total food budget. **R2** constrains the food consumption in case people cannot afford to buy it. Without the presence of this loop, if the budget constraint is avoided, all the available cereal in the market will be consumed. Therefore, there would be reduction of prevalence of undernourishment under realistic assumption in those years when the purchasing power was a constrained.

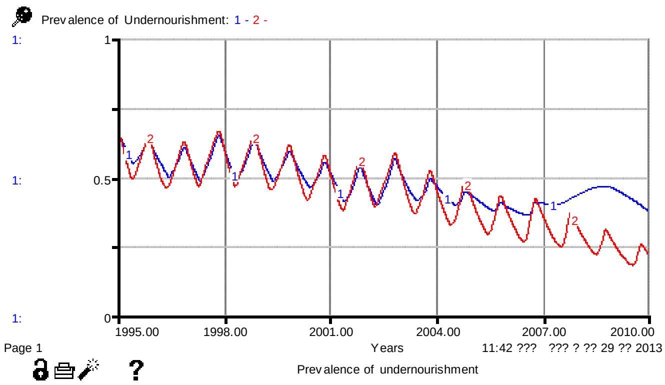


Figure4: comparison of the simulation results with the base run (1-blue) and when R2 is cut (2-red).

The model result shows that purchasing power was a constrained for food consumption mainly from 2005 to 2010. Hence, the prevalence of undernourishment has shown improvements in these years. Furthermore, the supply of food was insufficient to feed the total population under the given assumption.

Secondly, the reinforcing loop **R3** governs the food consumption through food supplies. The food demand of the population can only be addressed if there is sufficient food available (provided that people can buy their consumption). In the case when there is no sufficient food in the inventory (food supply) for the given food demand, people only consume the available food. Hence, the prevalence of undernourishment increases in this situation.

If the reinforcing loop **R3** is cut (there is no food supply problem, the people consume more than what is being produced, and this may only be done through additional imports), then we expect that the amount of food consumption will be relatively high during the years when the food supply was a constrained (1995-2008). As a result, the prevalence of undernourishment will be low in these years (improves). Since the oscillation of undernourishment shown in the base run has been generated by sudden drop of food supplies, we expect the oscillation to smooth in the model output.

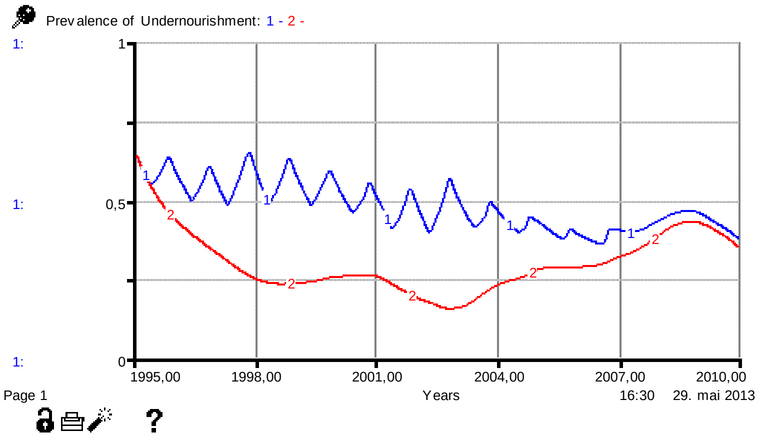


Figure 5: comparison of the simulation results of prevalence of undernourishment before (1-blue) and after (2-red) the loop R3 is cut.

As shown in the figure 5, the prevalence of undernourishment has shown significant improvement (decrease) especially from 1995 to 2007, during which the food supply was the main constraint. While the increase in the prevalence of undernourishment observed from 2008 to 2010 is associated with limited purchasing power caused by the scale up of food price rather than limited supply of food.

Thirdly, the balancing loop **B5** governs the dynamics of land degradation. Where the fertile cultivation land passes through the various stages of land degradation through which the inherent productivity declines. Without the presence of the balancing loop **B5**, the relative inherent yield as well as the actual yield is expected to be higher than the reference behavior.

We cut the balancing loop **B5**, by setting the top soil depth loss rate very small (10^{-10}), so that the average life time of the land in each cohort will be very high. The simulation results are shown in the figures below.

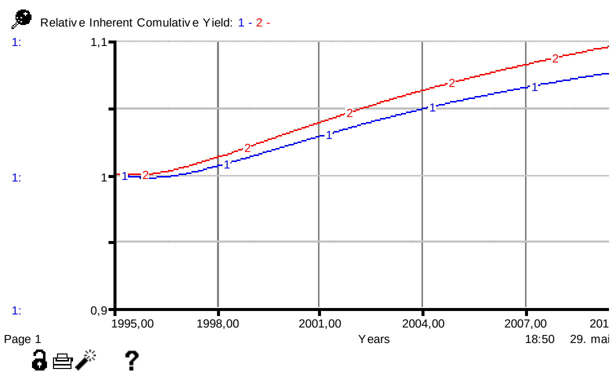


Figure 6 (a): Relative inherent / potential yield

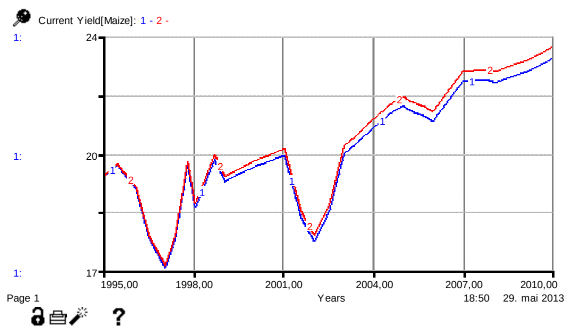


Figure 6 (b): Maize yield

Figure 6: comparison of simulation results of relative inherent yield, maize current yield when loop B5 is cut (1-blue) before and (2-red) after.

As shown in the figure 6, the simulation result of relative inherent yield (a) is above the simulation result of the base run. That is, arresting soil degradation relatively increases the inherent yield.

Similarly, the maize yield (b) has shown a better (higher) development compared to the base run. But while we compare the improvements of relative yield and maize yield over the simulation years, the improvement (difference between the base run and the simulation after the degradation is arrested) has increase more in the last five years than in the first five years. This implies arresting the degradation process is more effective in the long run than in the short run.

5. Model Analysis

5.1 Prevalence of Undernourishment, Desired Food Consumption, Food Demand and Supply

The main production deliveries lay between September and February and hence most of the food is available for consumption in these months. In the case of insufficient food in the inventory that could feed the food demand, the food consumption/food supply dropped sharply. The comparison of desired food consumption, food demand and food supply are shown in figure 7 below.

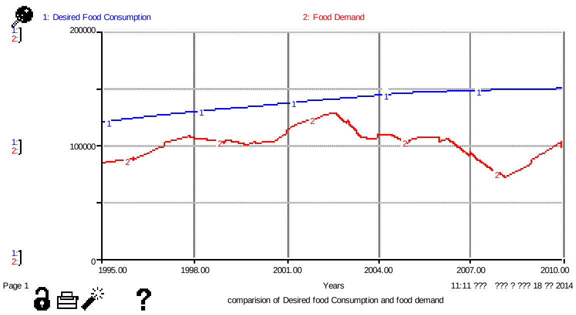


Figure 7(a): Comparison of desired food consumption and food demand

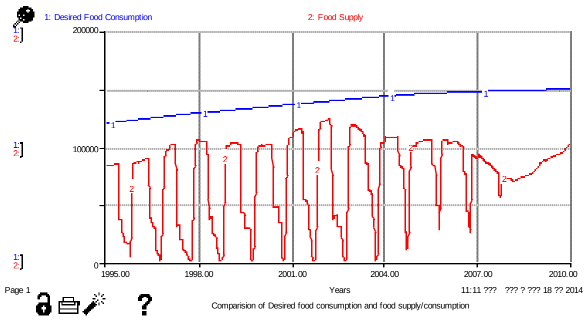


Figure 7(b): Comparison of desired food consumption and food supply/actual consumption

Figure 7: Comparison of desired food consumption (blue) with food demand (red) and food supply (red)

As shown in the figure above, both the food demand (economic access) and food supply (food availability) were well below the desired food consumption. The gap between the desired food consumption and the food supply/consumption interpreted in to desired nourished population and effectively nourished population respectively is used to examine the prevalence undernourishment. Hence, the gap between the desired and actual food consumption generally shows a declining trend justifying the declining trend of the prevalence of undernourishment.

The comparison of food demand and food supply shows that the food consumption was highly constrained by the availability of food, from 1995 to 2006, rather than the economic factor. The simulation graphs signify that even with the existence of purchasing power, all the food demand were not satisfied due to the limited supply of food from the market. The food supply has dropped below the food demand every year from 1995-2006 causing a recurrent dropped in food consumption which eventually resulted in oscillation on the prevalence of undernourishment. On the other hand, , the scale up in food price (from 2007 to 2010) caused the food demand to decrease considerably resulting in the stabilization of food demand relatively at lower level than the level of food supply. Hence in this period, the economic access was relatively tighter than the food supply eventually constraining the food consumption. This subsequently resulted in an increased in prevalence of undernourishment in 2007/08 before it adjusted to the trend in 2010.

5.2 Land Degradation and Productivity

In this section we opt to examine the effects of land degradation on changes of land productivity, food supply and prevalence of undernourishment. Sensitivity analysis is made on the average top soil loss rate which is the main determinant of land degradation. We refer the simulation behavior of the parameter with the value replicating the reference behavior, pink color (3), as the base run. The simulated behavior, with a 100 % of the parameter below or above the base run value, is represented by the blue (1) and the light red color (5) respectively. And the simulated behavior of the parameter, with 50 % below or above the base run value are represented by red color (2) and green color (4) curves respectively. The result reveals that the effect of land degradation on land productivity, food supply and prevalence of undernourishment is insignificant.

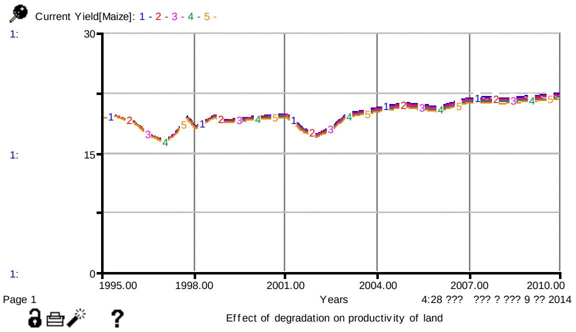


Figure 8(a): Maize yield

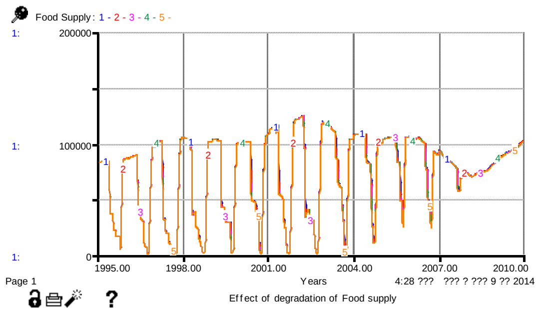


Figure 8 (b): Food supply

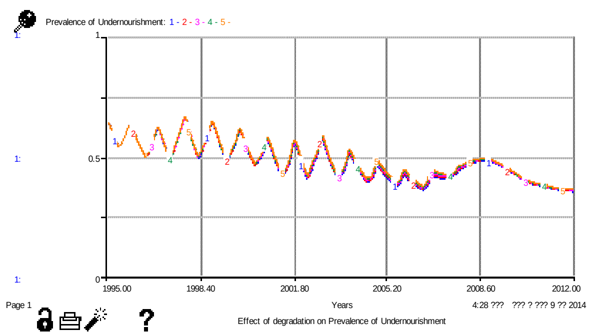


Figure 8 (c): Prevalence of undernourishment

Figure 8: Scenarios on topsoil loss rate relating land productivity, food supply and prevalence of undernourishment.

However, the above result does not necessarily imply land degradation has no significant effect on land productivity, food supply and prevalence of undernourishment in a longer time horizon. The stock of land in the degradation stages which is caused by degradation over hundred years contributes considerably to the average low productivity of the land. To examine this, we made four simulations runs based on assumed move of the land stock in the reverse direction of the degradation process i.e. at a time the chain: suitable land, moderately suitable land, marginal suitable land, and non-suitable land move one step towards the productive land. Whereas, the cultivated land of third run constitutes only high productive and suitable land, the cultivated land of the fourth run consist only high productive land. Figure 9 shows yield, food supply, and the prevalence of undernourishment of the four simulations.

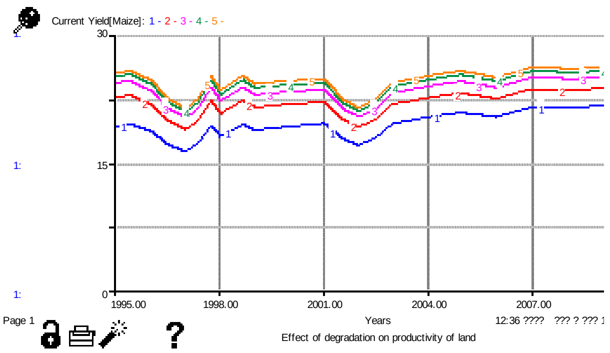


Figure 9 (a): Yield of Maize

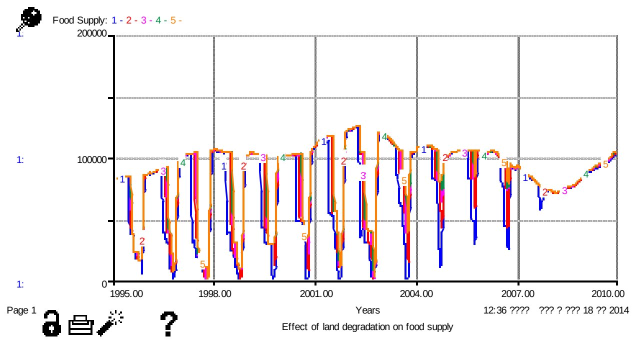


Figure 9 (b): Food supply (constrained by food demand)

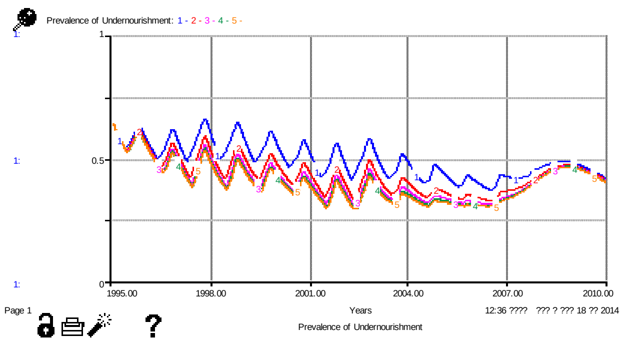


Figure 9 (c): Prevalence of undernourishment

Figure 9: Scenarios on the stock of lad in the degradation stages (1-blue base run, 2-red no non-suitable land, 3-pink no marginal, 4-green no moderately suitable land and 5- pink all productive land)

As shown from the simulation result, the graph of current yield of the four scenarios of moving the stock of degraded land to its preceding stage at a time, are all above the graph of the base run. The productivity of the land could improve considerably if rehabilitation measures are effective to move the non-high productive land stocks to the stock of high productive land. Around 20 percent of the current yield could be increased if rehabilitation is effective. As shown in figure (b), and (c) the increase in productivity can resulted in increase in food supply and decrease in prevalence of undernourishment in the case when purchasing power didn't constraint food consumption. However, this requires long time before one can see the effect in the form of an increase in land productivity.

6. Policy Analysis

This section focuses on examining future policy options. Two policies; capacity building in agricultural input supply, and land rehabilitation/conservation are the main future policy options examined. The causal loop structure of the policy model is presented in the figure below on top of the causal loop structure of the explanatory model.

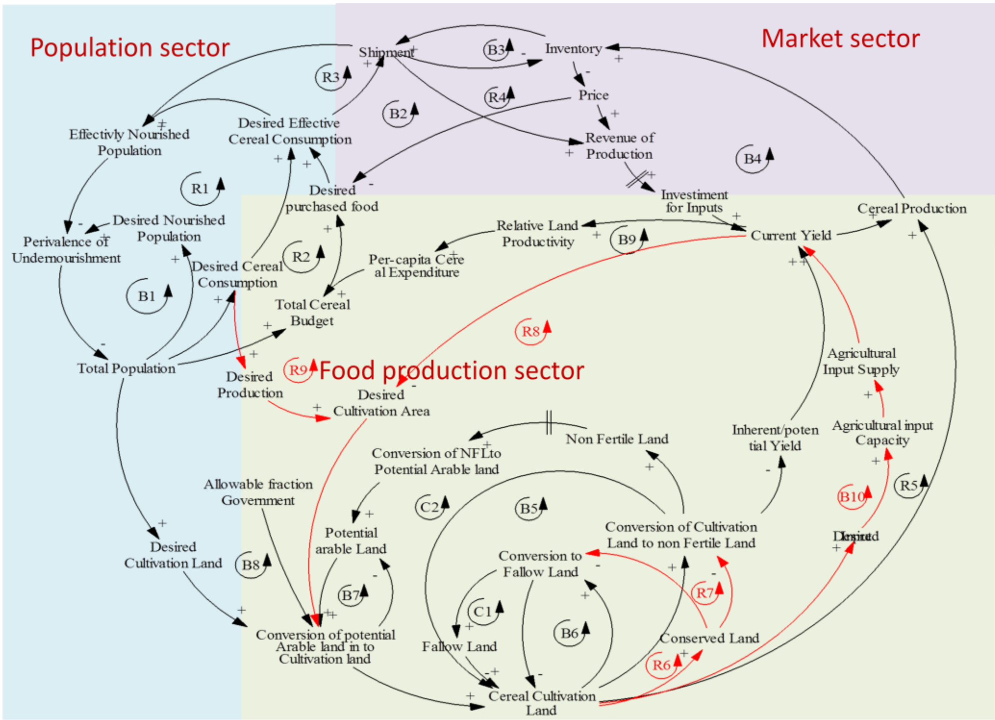


Figure 10: CLD of the explanatory model (black) and the policy model (red).

6.1 Land Rehabilitation/ Conservation

One of the main challenges or threats of food insecurity (reviewed) which has existed for decades and will prevail in the future is the poor management of natural resources. Soil degradation, the washing away of topsoil from cultivation land, needs to be stopped to increase the productivity of the land as well as to utilize it for generations. However, land rehabilitation is a slow process that takes years to change a non-suitable land into a productive land and vice versa. As a result, changes in productivity associated with degradation are unseen in a short period of time. But, the degraded land (stock) has contributed to the low average productivity (around 20 %) of the currently cultivated land. Hence, sustainable land management is demanding despite the long time horizon to wait to see policy effect.

The main objective of this policy option is to arrest soil erosion and ultimately rehabilitate the degraded land so that the productivity improves in the long run. Soil conservation techniques/methods generally include; soil and water conservation, construction of terraces, construction of check dams, cut-drains and micro-basin, afforestation and re-vegetation of fragile and hillside areas. Moreover, these technologies have stopped the loss of topsoil caused by water by reducing slope angle and length, increase infiltration, maintaining water stored in the soil and sediment harvesting (MARD, 2010).

The basic assumption in this policy option is that the applications of soil conservation methods gradually stop the topsoil loss from the land and that the land starts to gain topsoil through the natural decaying or sedimentation process, and consequently, become productive after considerable time of regeneration. We also claim that proper soil conservation and rehabilitation methods have effects that improve the fertility of the soil. As a result, effects of soil conservation will decrease the fallowing fraction of the land which, ultimately, increases the cultivated land (loops **R6** and **R7** in figure 10).

This policy is a fundamental solution to the food insecurity in Ethiopia, but it requires long time before one can see the effect in the form of an increase in land productivity. We simulate the model from, 1995 to 2050 and the policy is activated in 2015. The simulation results under this policy compared to the base run is presented in figure 11 below.

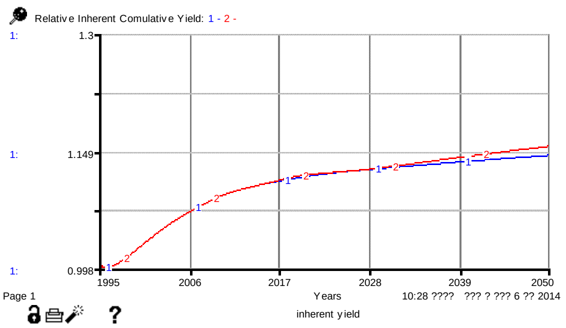


Figure 11(a): Relative inherent yield base run (blue), policy (red)

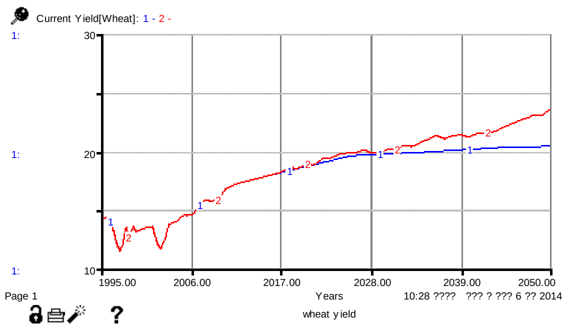


Figure 11 (b): Wheat yield base run (blue), policy (red)

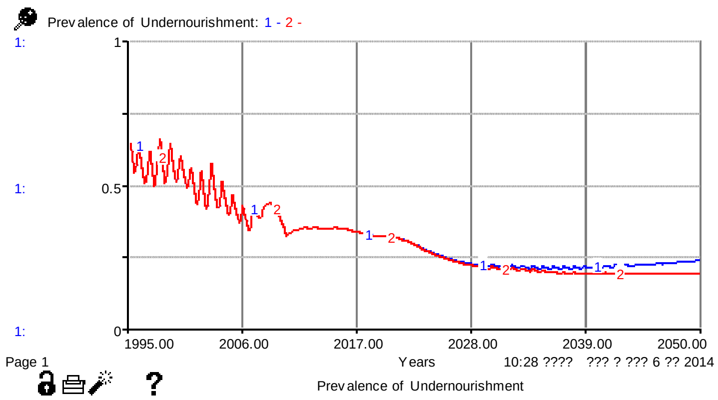


Figure 11 (c): Prevalence of undernourishment base run (blue), policy (red)

Figure 11: The comparison of the base run and the soil conservation policy for some selected variable

As shown from the simulation results, the policy require long time, from 2015 to 2036 (around16 years), to see considerable changes on relative inherent yield, current yield, and the prevalence of undernourishment. This is mainly because of the long time delay required for the rehabilitation process to improve land productivity.

6.2 Capacity Building on Agricultural Input Supply

The second policy option focuses on the increase of land productivity through the intensification of agricultural input supplies, mainly the application of improved seed and fertilizer. This policy requires capacity building on supplying these inputs either through production or import. The results of our analysis indicate that the coverage of improved agricultural inputs: improved seed and fertilizer was around 10 % and 54 % respectively in 2010. Hence, there is a considerable potential to increase the coverage of the inputs so the average productivity of the cultivated land will increase.

Thus, we claim that capacity building in agricultural input supplies will have a significant contribution in supplying the agricultural input to farmers. This in turn increases the total area coverage which, subsequently, leads to an increase in the average yield and production. Not only the increase yield provides increase in food availability in the market but, it also insures an increase in consumption by producers (loop **R9** and **B10** in figure 10 represents the capacity building policy).

We simulate the model from, 1995 to 2050. The simulation results of the added policy model show a progressive increase in land productivity after the activation of the policy in 2015. The increase in productivity causes an increase in food supply and consumption at large. The graph below allows the comparison of the base run and the policy run.

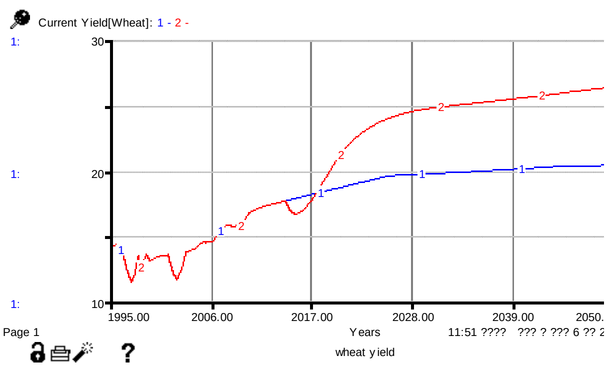


Figure 12 (a): Wheat yield base run (blue), policy (red)

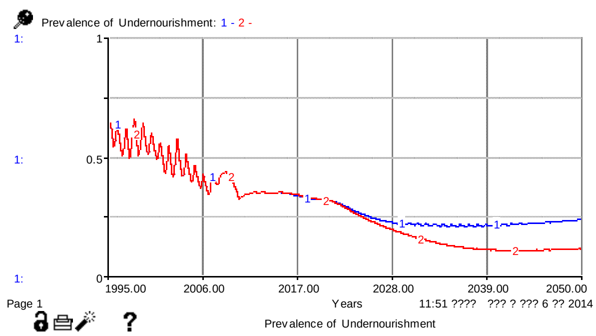


Figure 12 (b): Prevalence of undernourishment base run (blue), policy (red)

Figure 12: The simulation result of capacity building policy

The yields of land demonstrate a dramatic increment within five years of policy activation; figure 12 (a), resulting from the policy activation. It is very important to point out that the prevalence of undernourishment decreases, figure 12 (b), since the land productivity increased and subsequently caused an increase access to (limited access) and availability of food for producers. A change in relative yield explains 25 % of the change in the per-capita consumption hence actual food expenditure. However, the decrease in the prevalence of undernourishment could have decreased considerably provided that there was no economic constraint. And with this policy, the prevalence of undernourishment is expected to reach around zero by 2024 provided that every individual is economically capable of purchasing his/her consumption.

6.3 Synergy of Land Rehabilitation and Capacity Building Policies

It is demanding that Ethiopia need to produce more food to feed the population. Therefore combining short-term and long-term policies is vital for different implementation times. Since increasing production through its fundament solution, land rehabilitation/conservation policy, take long time to see its effect. The short-term policy, capacity building policy, needs to be implemented until the 2036 to ensure food availability. However smooth transition from capacity building policy to land rehabilitation policy is important after 2036. This is because the land rehabilitation policy has many advantages over capacity building policy such that; a) it can avoid subsidy cost of the government, b) it can help to save hard currency which would otherwise be used to buy chemical fertilizers and pesticides, and c) most importantly, it is a policy through which the food system will be more resilient to shocks and will be more sustainable. The simulation results of the combined policy when both are activated in 2015 compared to the base run is presented in figure 14 below.

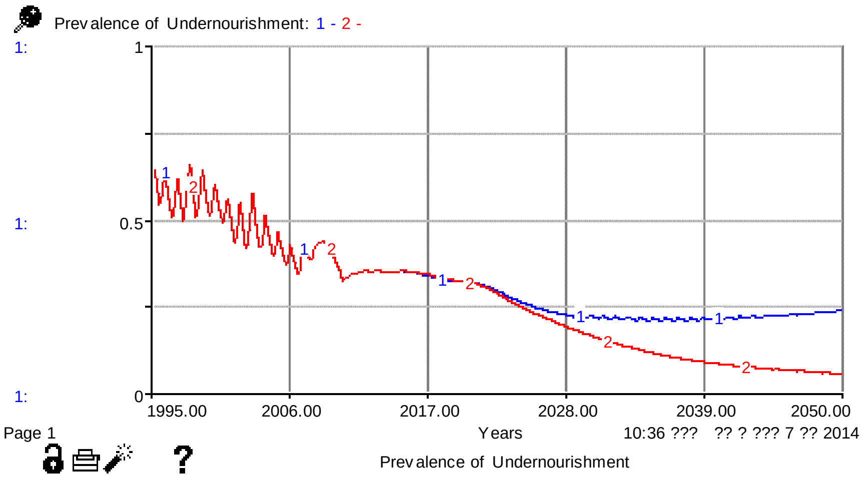


Figure 13: prevalence of undernourishment, model result of capacity building and land rehabilitation policies

7. Conclusion

The study of food security required examining the interaction of (a) the growing food consumption of the population, (b) the production of food through which the supplies are realized, and (c) the market by which the price and budgets determined the actual access of food. The model simulation results showed that both the availability of and access to food has been the main constraints of food consumption and/or food security at large. Besides, degraded land has contributed considerably to the average poor productivity of the land. Thus, it is demanding to steadily increase food supplies and purchasing power of the population in the future in order to ensure food security. Policy analyses showed that future policy options such as land rehabilitation and capacity building for skilled use of agricultural inputs such as seeds and fertilizer need to be combined carefully to account for their different implementation times. Modeling the interaction of the soil nutrient recycling & productivity, in addition to analyzing endogenously the economy of the country in general and, income and expenditure distribution in particular are potential research areas.

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9. Appendix: Model Structures

9.1 Population sector

The need for modeling the population dynamics as a basis for examining the food consumption of the population is evident. Moreover, the size of the population is evidently important for examining resource utilization and distribution such as land. For easy representation and study of the population dynamics, a generic model is developed. We divided the population into five cohorts, the children cohort (age 0-4), the school age cohort (age 5-14), the fertile age cohort (age 15-29), the fertile age cohort (age 30-49), and the elderly cohort (age above 49). In the model, out flows: death rate and net migration, and an inflow birth rate are the flows regulating the population stocks.

9.1.1 Food Consumption

We used two terminologies to express the food consumption need of the population namely; desired food consumption and food demand. We refer desired food consumption as the need of food based on the minimum daily calorie requirement of the individual. While, when the desired food consumption is materialized in the purchasing power of the population, we call it food demand. Estimated energy requirement are highly sensitive to individual's specific characteristics such as: gender, age, body size, presumed body composition, living environment and physical activity. However, the average energy requirements could be set for groups or classes of individuals who have similar characteristics.

The adult-equivalent calorie requirement is based on mean calorie requirement of a reference adult man. Conversion factors are defined as a ratio between the calorie requirement for each age group, gender, and that of the reference adult. Hence, using the conversion factors (ratios), the calorie requirement of various age groups and sex are computed. The adult-equivalent scale is useful tool for narrowing the difference between demand estimates found from the use of average per-capita consumption and real consumption demands. We used adult-equivalent daily calorie requirements instead of per-capita daily calorie requirement.

From the population sector, we used the five stocks to model calorie consumption. These population stocks consists of both genders in similar age groups whose desired calorie requirements is similar. However, in each stock the calorie consumption of the two genders are computed separately, depending on their proportion in the total stock. Moreover, the average age in each stock is used to determine the adult-equivalent proportion (Ayenew, 2013). Figure 15 shows the model structure used for the dynamics of population and cumulative adult-equivalent fraction of the entire population.

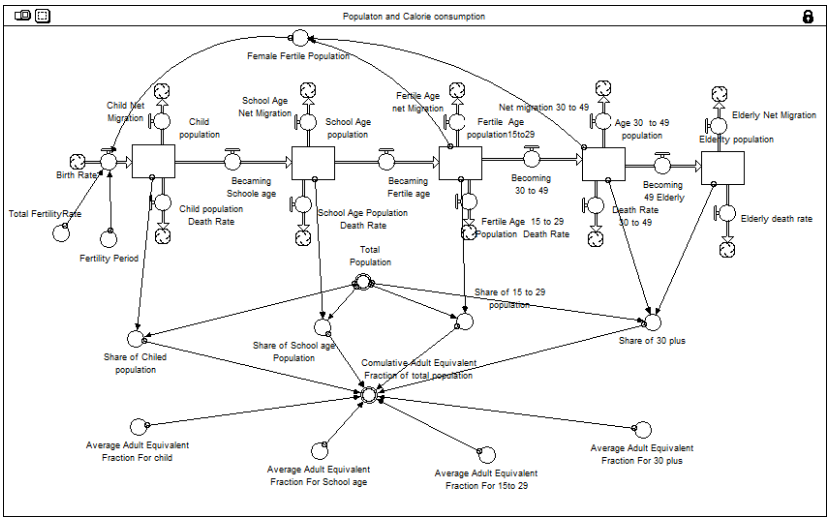

Figure 15: General model structure of population age cohorts and cumulative adult-equivalent fraction.

9.2 Food Production Sector

9.2.1 Land Use and Productivity

Agricultural production (food) is facilitated by the use of productive land, the required agricultural conditions, and the addition of inputs to the system such as fertilizers and pesticides. The amount of agricultural production depends directly on the size of the cultivated land and the fertility of the land. As a result, it is necessary to study the dynamics of land use and its fertility to explain the dynamics of food production.

Four main dynamics are identified in land use for food production. These changes comprises of the conversion of potential arable land to cultivated land, conversion of cultivated land in-to fallow land and the vice versa, conversion of cultivated land in to non-fertile land, and, finally, the conversion of non-fertile land in to potential arable land (the reverse process sometimes may be irreversible). These changes are governed by different rules and have different time horizons.

Associated with the four main dynamics, four stocks are identified. The stock of potential arable land-consists of land that is suitable for rain-fed agriculture, the stock of cereal cultivated land-consists of land currently being cultivated, the stock of fallow land-consists of cultivation land that is temporarily fallowed for rehabilitation purpose or due lack of rainfall, and the stock of non- fertile land-consists of land highly eroded and become unproductive after an intensive period of cultivation.

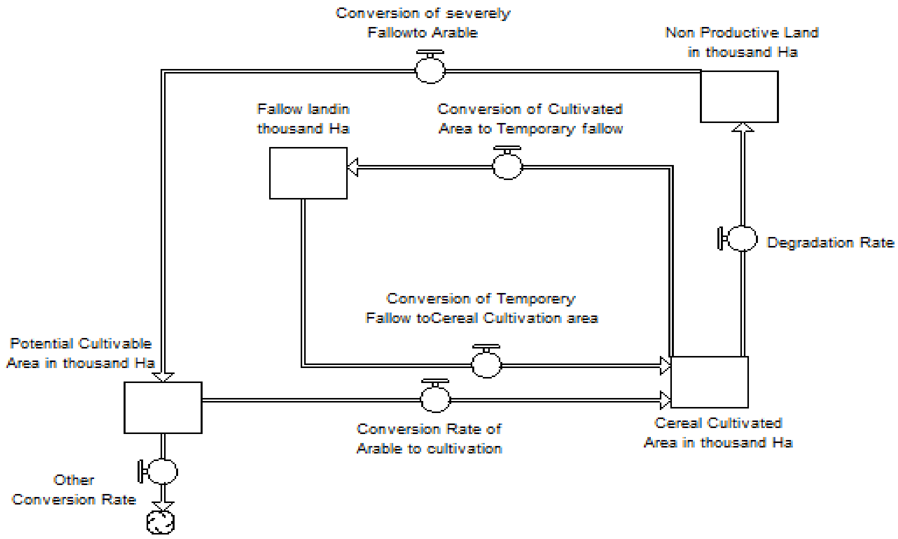

Figure 16: Stock and flow diagram of the main land use model

The need for access to new land for cultivation has been evident in Ethiopia due to high population growth and loss of cultivation land associated with land degradation. When more people need to produce their food and make a living from land, potential arable land has been continuously used for cultivation which determines the conversion rata of arable land in to cultivated land. Average fallowing fraction and the effect of rain fall on the cultivated area is used to define the conversion of cultivated land into fallow land, and an average time to remain fallow is used to define the remaining flows.

Evidences show that with the resettlement strategy of ensuring food security for a chronically food insecure population resulted in the conversion of potential arable lands to cultivation areas in the short run. And with the absence of good soil management and water conservation practices in the new settlement area, intensive cultivation would result in the degradation of the natural environment particularly, soil which ultimately leads to food insecurity in the long run. This process with a significant delay, conceptually coincides with the '*shifting the burden archetype*[3].

The second most important dynamics lays on the transformation of fertile cultivated land in to non-fertile land within the stock of cultivated land by way of gradual degradation process. Soil erosion is a natural process of land degradation through which losses in soil productivity comes due to physical losses of the top soil, reduction in rooting depth, and removal of plant nutrients. Accelerated soil erosion (due to the human activities), causes the erosion rates to exceed the threshold soil erosion rate. When the soil loss rate exceeds the soil formation rate (threshold soil erosion value) the net physical loss of top soil cause severe degradation in the long run, that ultimately change the fertile cultivated land into non-fertile land. Poor land use, poor soil management, and poor farming (or cropping) practices are the main anthropogenic factors governing the accelerated soil erosion (Denboba, 2005, Eaton, 1996).

We identified five classes (stocks) of cultivation land called suitability classes as follows:

- High productive land (HP): soil water is not limiting and production is 100 percent.
- Suitable (S): soil water becomes limiting and there is at least 20 percent decrease in yield potential.
- Moderately suitable (MS): soil water becomes limiting and there is at least 40 percent decrease in yield potential.
- Marginal suitable (ms): soil water becomes limiting and there is at least 60 percent decrease in yield potential.
- Not-suitable (Ns): soil water becomes limiting and there is at least 80 percent decrease in yield potential (Kassam et al., 1991).

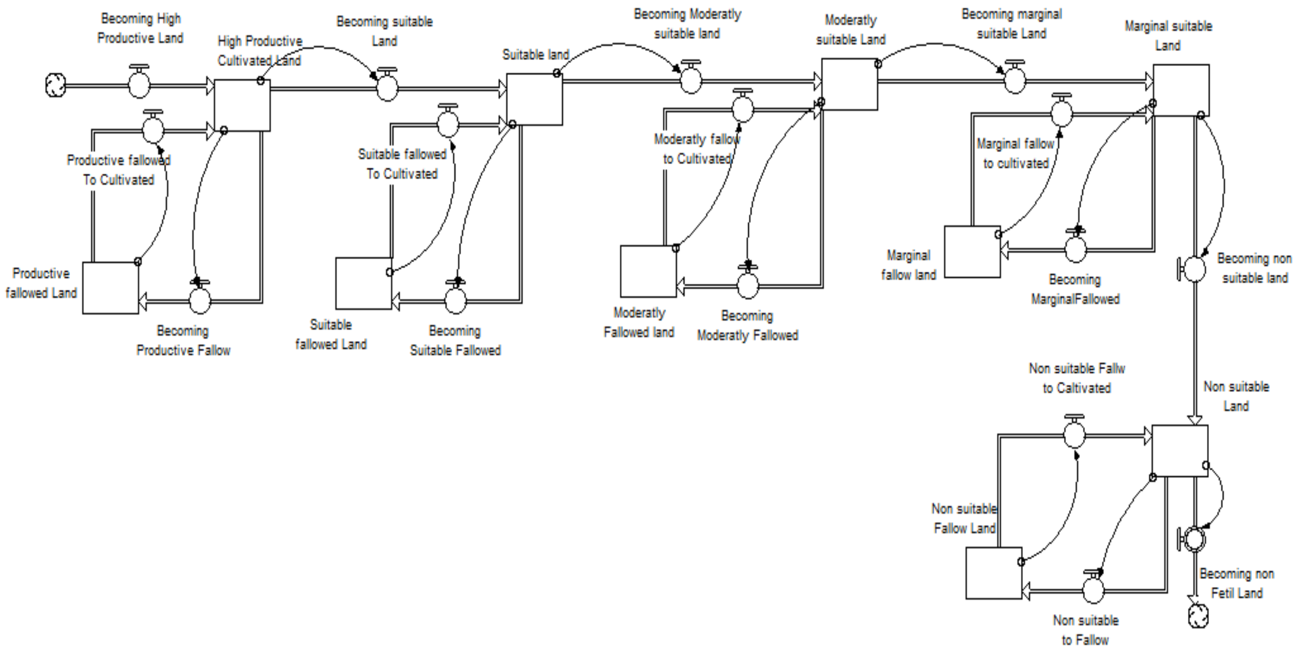

Figure 17: the stock and flow structure of the degradation dynamics within the stock of cultivated land

[3]Archetypes in general are diagnostic tools which insight into the underlying structure from which the problematic behavior originates. Shifting the Burden archetype in particular illustrates the tension between 1) the attraction (and relative ease or low cost) of devising ***symptomatic solution*** to a visible problem and 2) the long-term impact of ***fundamental solution*** (takes long time, patience, requires relatively large up-front commitment of funds) aiming at underlying structure that is producing the problematic behavior at the first place. Selecting the *symptomatic solution* rather than the *fundamental solution* produces instant gratification (sort-term solution) and has an effect to perceive little need to pay any more attention to the *fundamental solution*. However, in the long run the problem gets much stronger (aggravated) than at the first time and needs relatively more efforts to alleviate (Braun, W. 2002).

Since erosion takes place on soils of varying depth, with a net loss rate, it results in the transformation of high productive land into suitable land. And the conversion of other land such as: suitable and moderately suitable, towards moderately suitable and marginal suitable respectively. The depth of top soil at which the yield would start to be negatively affected by soil depth is called *critical maximum depth*. The critical maximum depth depends on the type of crop and climate of production. Once the critical maximum depth has been achieved, the productivity loss is linearly related to the depth of top soil until the soil becomes too shallow to produce any crop at all (Kassam et al., 1991, Sutcliffe, 1993). The depth of top soil at which crop production is abandoned, is called *critical minimum depth*. If the yield potential decreases to below 20 percent of the inherent yield that would be obtained at the maximum critical depth, then the land is considered to be useless or unproductive (ARS, 2002, BGRS, 2003, Kassam et al., 1991). We used average top soil depth loss rate for the formulation of flows between the stocks suitability classes.

9.2.2 Land Fertility

The dynamics of soil fertility is based on the dynamics of land degradation stages, the application of inputs, and the effect of rainfall. As the land moves from the stock of high productive to the stock of non-suitable land, in each successive stage, its potential yield decreases by 20 percent. We consider the potential yield at the maximum critical depth (or a depth higher than the maximum critical depth) to be the inherent potential yield. We use a weighted sum of the inherent potential yield of each suitable land type to calculate the cumulative inherent potential yield of the total cultivated land. Depending on the use of agricultural inputs, we classify the yield types obtained from the inherent potential yield as; *improved seed and fertilizer applied*, *traditional seed only fertilizer applied*, and *traditional seed without fertilizer i.e.* sequentially, use of both improved seed and fertilizer, only fertilizer used, and neither fertilizer nor improved seed applied. Also effect of rainfall and intensity of fertilizer applied are also considered (Ayenew, 2013)

9.3 Market Sector

The concept of cereal/food market is much more complex than computing the supply and demand of food for the population. In this section we analyze the main variables involved in the food/cereal market such as: food supplies, food demand, imports, shipments, calorie consumption, expenditure, purchasing power, food losses, producer & consumer price etc.

9.3.1 Desired Food consumption

In the population sector, we have modeled the average adult-equivalent fraction of each age cohorts. We worked out the share of the cohorts from the total population to compute the cumulative adult-equivalent calorie fraction of the entire population. Multiplying the cumulative adult-equivalent calorie fraction with the daily adult-equivalent Kcal consumption of a person results in the national cumulative daily desired adult-equivalent calorie consumption. The cereal types and their corresponding calorie per 100 gram are used from food composition table for the conversion of desired daily calorie consumption (adult equivalent) in to desired food consumption.

9.3.2 Food Access

The desired food consumption materialized in the purchasing power of the population results in food demand. As a result, it is important to discuss the household per-capita expenditure and food consumption patterns to determine the food demand. The most important parameters in this section are the amount of expenditure (nominal expenditure) and the food share of the expenditure. We use average annual per-capita expenditure and cereal expenditure share in the model to compute annual average per-capita budget for cereal. The budget allotted for food computed with food price results in the actual food demand. The food consumption is the minimum of the food demand and the available food in the market.

9.3.3 Food Availability: Cereal Inventory, Food Supplies and Shipments

For price analysis, it is demanding to deal with the accumulation of cereals in a stock called cereal inventory. Generally the inventory represents any accumulation of food/cereals either for direct consumption (by producers) or for sale (retailers and wholesalers). Thus the amount of cereal in the inventory is altered by two main inflows namely cereal delivery (comprises of: domestic small scale farmers' Meher[4] and Belg[5] production, and net import) and commercial farm cereal delivery, and three main outflows, namely consumption shipment, industrial shipment and post-harvest loss.

9.3.3.1 Private Holders' Meher Production

Meher cereal production by private holders constitutes around 92-95 % of the total production (CSA, 2011). It is the main domestic supply of food in the market. However, relatively small amount of the production is delivered to the market, for sale, for the urban population. CSA (2011) Crop and livestock product utilization survey reported that 66.98, 13.83, 14.66 % of the total cereal production serves for household consumption, seed and sales respectively by producers. While the remaining proportion serve as wages in kind, animal feed and others. It should be noted that the private holders Meher cereal production delivery is the only inflow to the cereal inventory which is endogenous to the model.

9.3.3.2 Commercial Holders' Cereal Delivery

Commercial cereal production constitutes around 3-5 % of the total production. Comparison of commercial, Belg and Meher cereal production and their respective shares are shown in a table below.

year	Commercial Cereal production (both season)	Belg Cereal production private	Meher Cereal production private	total Cereal production	Commercial cereal share (both season)	Belg cereal share	Meher cereal share
2008	3942.28	6942	144964.06	155848.34	0.0253	0.044543	0.930161
2009	6019.59	6942	155342.28	168303.87	0.0358	0.041247	0.922987
2010	6112.92	11736	177613.37	195462.29	0.0313	0.060042	0.908684

Table 1*: Comparison of domestic production of cereals*

Source: Author computation from CSA surveys

9.3.4 Shipments: Consumption Shipment, Post-Harvest Loss

Cereal shipment represents the depletion of the cereal inventory for human consumption. This shipment includes the consumption of cereal by producers (farmers), and consumers. The important factor in determining the shipment for consumption is the annual food demand computed above. Therefore, cereal shipment is a minimum function of food/cereal demand and a first order adjustment of the cereal inventory (with adjustment time). Industrial shipment is estimated by the industrial delivery based on the data analysis (Ayenew, 2013). Estimate of Post-Harvest loss are considerably high, for example, depending on the type of post harvest handling, losses could range from 5 to 19 % for maize, from 6 to 26 % for millet, from 6 to 23 % for wheat and from 5 to 20 % for Tef (Gabriel, 2003-Proceedings of the Food Security Conference p. 221).

9.3.5 Food Price

Food market and pricing in Ethiopia involves producers and consumers. Domestically produced cereals must be transported from the place of production to the place of consumption with the involvement of different actors. For the purpose of our analysis, we have identified two food/cereal prices namely the producer price and the consumer price. We call the price of cereals at which the producers sell their products to be producer price. Consumer price refers to the price of cereals after other actors (wholesalers or retailers) being involved and transported in to urban areas. In the model, we identify the producer price as a stock adjusted with the indicated producer price (computed with inventory ratio, inflation rate and producer price) and the producer price itself.

Cereals bought from the producer market by rural assemblers; need to be transported into the urban areas. The transaction involves brokers, regional assemblers, wholesalers, and retailers. Moreover, transport costs and available market networks especially road networks are considered in the adjustment of the consumer price on top of the mark up fraction. The model structure of cereal inventory, supplies, shipments and prices is given below.

[4]Meher season (main rain) is the long rainy season that occurs from June to September. This season is the most convenient (or ideal) growing condition for most crops. Meher production (produced by Meher season rain) is the crop that is harvested from September till February. [5]Belig (short rain) is referred as small but timely, rainy season which normally occur from February to May. But it occurs only in limited areas of the country. Belg season crop (produced by Belg season rain) is the crop that is harvested during the months of March to August (CSA, 2011).

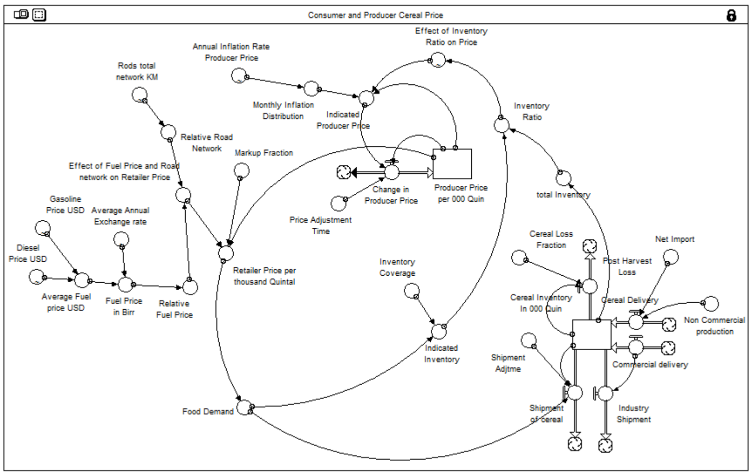

Figure 17: The model structure representing the market sector.

9.3.6 Revenues, Agricultural Inputs and Yield

In our model based analysis, we also addressed the interaction of the variables; (a) producer price, (b) revenue obtained from the sale of production, (c) agricultural input investments (chemical fertilizers and improved seed), and (d) the yield per hectare (or production in general). We represent cash (local currency) by a stock, having one inflow 'revenue' and one outflow 'revenue spending rate '. The inflow (revenue) is defined as the amount of all food sale shipments multiplied with the producer price of each cereal type of the given year. Part of the revenue, obtained from the sale of production, accumulated for one year, is expected to be invested for agricultural input.

We defined relative attractiveness which is used as an attractiveness measure of input investment so as to examine the benefits of applying improved agricultural inputs. Relative attractiveness of investment is defined as the ratio of change in revenue obtained from the use of agricultural input to the change in cost of the input applied (Ayenew, 2013). Finally, joining the input variables for the current yield; relative inherent yield from the land use sector, effect of rainfall (exogenous), relative fertilizer used together with its elasticity, and average yields of cereals weighted with the three input coverage i.e. both fertilizer and improved, only fertilizer, and neither fertilizer nor improved seed (traditional seed) resulted in the current cereal yield.