SYSTEM DYNAMICS MODELING OF AGRICULTURAL VALUE CHAINS: THE CASE OF OLIVE OIL IN TURKEY

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ABSTRACT

SYSTEM DYNAMICS MODELING OF AGRICULTURAL VALUE CHAINS: THE CASE OF OLIVE OIL IN TURKEY

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In recent decades, agricultural commodity and food price fluctuations reveal the importance of understanding the agricultural value chain dynamics and making policy recommendations for sustainable development. The modeling purpose in this study is twofold: (1) to understand the price, supply and demand dynamics along the agricultural commodity value chains (2) for the specific case of olive oil value chain in Turkey, to make policy and scenario analysis with the focus of economical sustainability. In line with these purposes, the Agricultural Commodity Value Chain Model is constructed with system dynamics modeling methodology. The model is unique in terms of simultaneously (i) including both the agricultural supply chain and the agricultural value chain structures, (ii) considering the four major market elements, price, demand, supply, and capacity, endogenously, and (iii) considering complex nonlinear relationships among the price levels in different stages of the agricultural value chain. Using this modeling framework and a stylized parameter setting, we first conduct a numerical study and analyze the performance of two sets of value chain interventions, namely, technology investments and financial aid improvements, in mitigating the price fluctuations. Then, the model is adapted to the case of olive oil value chain in Turkey. By utilizing the historical data between years 2007-2018, the model is shown to be valid to represent the behavior of the olive oil value chain in Turkey. Using the validated model, a set of simultaneous policy and scenario analyses are conducted for years 2019-2023 and the impacts of policies on economic indicators are presented.

Keywords: System dynamics, Simulation, Operations research in agriculture, value chain, olive oil

ÖZ

TARIMSAL DEĞER ZİNCİRLERİNİN SİSTEM DİNAMİKLERİ İLE MODELLENMESİ: TÜRKİYE ZEYTİNYAĞI ÖRNEĞİ

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Son yıllarda gıda ve tarım ürünlerinde yaşanan fiyat dalgalanmaları, tarımsal ürünlerin değer zinciri dinamiklerinin anlaşılması ve ekonomik sürdürülebilirliğinin sağlanması için politika ve senaryo analizleri yapılması ihtiyacını arttırmıştır. Bu ihtiyaçtan yola çıkarak yaptığımız modelleme çalışmasının iki temel amacı vardır: (1) Tarım değer zincirlerindeki arz, talep ve fiyat dinamiklerini anlamak, (2) Türkiye zeytinyağı değer zincirinin ekonomik sürdürülebilirliğinde iyileşmeler sağlanabilmesi için uygulanabilecek politikalar ve muhtemel senaryolarla ilgili sayısal analizler yapmak. Bu amaçlar doğrultusunda, sistem dinamikleri yöntemi kullanılarak Tarımsal Değer Zinciri Modeli kurulmuştur. Bu modelin mevcut sistem dinamikleri literatürüne katkısı, (i) tarımsal tedarik zincirini ve tarımsal değer zincirini bir arada içermesi, (ii) dört temel ekonomik değişken olarak fiyat, talep, arz ve kapasite değişkenlerinin tümünü içsel (endojen) olarak kabul etmesi ve (iii) değer zincirinin farklı aşamalarındaki fiyat seviyeleri arasındaki doğrusal olmayan karmaşık ilişkileri dikkate alabilmesidir. Kurulan bu model ile, ilk önce, hipotetik bir veri seti kullanılarak sayısal analizler yapılmış, seçilen teknoloji yatırımlarının ve finansal desteklerin iyileştirilmesinin zincirdeki fiyat dalgalanmalarına olan etkisi değerlendirilmiştir. Daha sonra bu model, Türkiye'deki zeytinyağı değer zincirine uyarlanmıştır. 2007-2018 yılları arasındaki veriler kullanılarak, modelin Türkiye'deki zeytinyağı değer zincirinin davranışını temsil edebildiği ve geçerli olduğu gösterilmiştir. Geçerliliği gösterilen bu model ile, 2019-2023 yıllarına dair eş zamanlı politika ve senaryo analizleri yapılmış ve politikaların ekonomik göstergelere olan etkileri sunulmuştur.

Anahtar Kelimeler: Sistem dinamikleri, Benzetim, Tarımda yöneylem araştırması, Değer zinciri, Zeytinyağı

To my complementary dual, Kaan Balkan...

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LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization of the United Nations
ILO	International Labour Organization
IOC	International Olive Council
M4P	Making Markets Work Better for the Poor
MAF	Ministry of Agriculture and Forestry of Turkey
TÜİK	Turkish Statistical Institute
TÜSSİDE	Turkish Management Sciences Institute
UN	United Nations
USAID	United States Agency for International Development
WB	The World Bank

CHAPTER 1

INTRODUCTION

Food price fluctuations along with increasing volatility and uncertainty in food prices have drawn significant attention since the global food price inflation crisis of 2007–08. The measures of volatility show that food price volatility in the last 50 years has reached its highest level (FAO, 2017). Volatile prices pose significant problems for farmers and other participants of food and agricultural chains who are under the risk of losing their investments if prices fall while they develop their strategies depending on high price levels (FAO et al., 2011). On the consumption side, food price inflation can also be a major problem, especially in middle-income countries, where many consumers spend half of their budget for basic foods (FAO et al., 2011). Instability in food prices slows down the economic growth and also the structural transformation which is the pathway out of rural poverty (Timmer, 2017).

In recent years, the value chain has become as one of the main paradigms in development thinking and practice (FAO, 2014), and value chain upgrading interventions have emerged as a dominant approach to rural development (Vicol et al., 2018). As a key framework, the value chain perspective guides us in understanding the processes; how inputs and services are brought together and used to grow, transform, and produce a product; how the product moves physically all the way from producer to customer; and how the "value" increases along the chain (Webber an Labaste, 2010).

In the context of food and agricultural systems, an agricultural value chain "identifies the set of actors and activities that bring a basic agricultural product from production in the field to final consumption, where at each stage value is added to the product" (Bolzani et al., 2010). The agricultural value chains are fundamental to the survival of human society, the growth or maintenance of regional and national economies, and the wealth and welfare of individual producers (Higgins et al., 2010). Understanding and explaining how the value of agricultural commodities emerges along the agricultural value chains is a complex research problem. In this study, considering the complexity of agricultural value chains and focusing on the Turkish olive oil case, we aim to understand and explain the agricultural value chain dynamics and make quantitative policy and scenario analysis for the Turkish olive oil value chain through system dynamics modeling.

Turkey, with its geography and biodiversity, is home to several agricultural commodities of strategic importance. One strategically important agricultural product of Turkey is olive oil, and hence its raw material, olive fruit. Olive oil is strategically important, because Turkey is one of the top five largest olive oil suppliers of the world, satisfies the domestic demand to its fullest extent and exports olive oil to more than 50 countries. During the years between 2005 and 2017, with the help of government incentives, the number of olive trees has increased by almost 54% and planted acreage has expanded by almost 28% in Turkey. Olive oil production in Turkey continues to upsurge, providing surplus for increases in export figures. Despite this positive outlook, stakeholders along the value chain, from the olive farmers to consumers, have concerns about the price fluctuations in the market, and hence economical sustainability of the industry. In recent years, consumer prices for olive oil have unexpectedly and dramatically increased despite increasing olive harvest volumes. The stakeholders have been worrying about the fact that, in the near future, due to high level of consumer prices, olive oil demand may decrease and then there may be a high level of excess olive oil supply. Consequently, prices may dramatically go down and hence the economical sustainability of the olive oil industry in Turkey may be imperiled.

The existing literature on value chain analysis and agricultural value chain development, as presented in Chapter 4 in detail, can be considered to be rich: there are several guidelines and reports on value chain analysis and agricultural value chain development, and there exist several publications which present agricultural value chain analyses and agricultural value chain development projects for specific products in specific countries. In traditional agricultural value chain analysis approaches, quantitative analyses mainly focus on calculating costs, revenues and profitability margins along the chain. On the other hand, qualitative analyses deal with the strengths, weaknesses, opportunities and threats along the chain and propose a set of recommendations. These traditional approaches seem to be limited in answering the questions about: "(i) where to invest, and (ii) what will be the economic impact on different chain actors from specific interventions?" (Rich et al., 2009). On the other hand, previous applications of operations research in agriculture focus on decomposing the problem into components and then identifying the optimal solution for each component; however, this approach has some limitations in agricultural value chains which include complex interacting elements (Higgins et al, 2010). That is, policy analysis for agricultural value chains requires both systemic and quantitative approaches to assess the impacts of value chain interventions. In this study, in order to understand the complex dynamics along the agricultural value chains and provide a quantitative analysis for the olive oil value chain in Turkey, we utilize system dynamics modeling which is one of the complex system science methods as Higgins et al. (2010) recommend.

Considering the dynamic problem of fluctuating and abruptly increasing prices along the agricultural commodity value chains and the sample case observed in the olive oil value chain in Turkey, we have come up with two major modeling purposes:

- to understand the price, supply and demand dynamics along the agricultural commodity value chains and to explain them analytically and mathematically via a system dynamics model,
- to make policy and scenario analysis for the specific case of olive oil value chain in Turkey with the focus of economical sustainability.

Our dynamic hypothesis is that different price levels along the agricultural value chains (i.e. raw fruit / plant price, processed bulk food price, packaged food retail price) are not the sole summation of the relevant individual costs and profit margins. When one price level undergoes an external effect, such as a policy decision in governmental financial supports or a change in world market conditions, other price levels along the value chain are affected in a nonlinear manner. These changes may lead to abrupt and unexpected increases or decreases in other price levels due to their endogenous structures and embedded feedback loops. Even when the corresponding external effect diminishes, stabilization of prices may take too long and damage the value chain actors.

The value of our work can be assessed distinctly with respect to the research domain: for the agricultural value chain analysis literature, our work contributes to the domain where the number of quantitative and prospective policy analysis approaches are limited. When the practical contribution of the work is considered for the policy makers in Turkey, this study presents a new perspective for agricultural value chain development since it is a unique application of system dynamics in agricultural value chains which sets Turkey as the problem environment.

In the system dynamics literature, there is a plenty of studies dealing with the problems in agricultural commodity markets and agricultural value chains, which are detailed in Chapter 4. As for the main contribution of our study to the existing system dynamics literature, we develop a unique system dynamics model for agricultural value chains incorporating the three characteristics simultaneously:

- including both the supply chain and the value chain structures,
- considering the four major market elements, which are price, demand, supply, and capacity, endogenously,
- considering complex nonlinear relationships among the price levels in different stages of the agricultural value chain.

The methodology followed throughout the study can be summarized as follows: in line with our modeling purposes, we develop a system dynamics model, Agricultural Commodity Value Chain Model, which consists of nine interacting modules representing the agricultural value chain and supply chain structures: Planting, Harvesting, Processing, Packaging, Demand, Export, Fruit Price Setting, Bulk Food Price Setting and Retail Price Setting. The model is built with the system dynamics software Stella Architect. This model has a rather generic nature and is applicable for the agricultural commodities with specific characteristics under the defined assumptions, as detailed in Chapter 5. The model has undergone several structural validity tests; and then, for a certain special case using a synthetic data set, the use of the model is demonstrated as a framework for policy analysis (see Chapter 6). Then the model is applied to the case of olive oil value chain in Turkey. For each module, dynamics of the historical data are presented, modifications in the model structure are justified, automated parameter calibration procedures are explained, and parameter settings for the whole model are completed. Then the olive oil value chain model has undergone relevant model validity tests: direct structure tests, structure oriented behavior tests and behavior pattern tests. As the result of these tests, the model is shown to be valid for its purpose. As the final step, simultaneous policy and scenario analyses are conducted with the validated model. For each policy, price levels along the value chain, value added at the end of each operation, and earnings of the stakeholders are calculated and compared as well. Among the three sets of policies analyzed, making productivity investments and empowering cooperative action along the chain are found to be creating relatively more value compared to the direct financial supports. The results of the policy analyses are envisioned to provide new insights and implications for the policy makers in the field.

The rest of the study is organized as follows: In Chapter 2, relevant products, processes and stakeholders along the olive oil value chain are presented. Additionally, the situation both in the world and Turkish olive oil markets are summarized, and relevant literature on the world and Turkish olive oil markets are reviewed. In Chapter 3, our research problem is defined with our modeling purposes and dynamic hypothesis. In Chapter 4, first the relevant literature on agricultural value chain research is presented. Then, various operations research approaches on agriculture are exemplified and relevant system dynamics studies are reviewed in detail. In the final part of the chapter, our expected contribution to the existing literature is stated. In Chapter 5, our generic agricultural value chain model is explained. The structure of the model with its modules, stock-and-flow diagrams, variables, and all analytical and mathematical relationships are presented in detail. In Chapter 6, a quantitative policy analysis is conducted for the purpose of mitigating the price fluctuations along an agricultural value chain. The analysis is demonstrated for a special case using a synthetic data set. In Chapter 7, the agricultural value chain model is modified and applied to the specific case of Turkish olive oil value chain. In Chapter 8, the procedures and results of the relevant model validation tests are presented for the Turkish olive oil value chain model. In Chapter 9, quantitative policy and scenario analyses are conducted for the improvement of the Turkish olive oil value chain. The study is concluded and future research issues are discussed in Chapter 10.

CHAPTER 2

OLIVE AND OLIVE OIL

The purpose of our study is to understand the dynamics in agricultural value chains and to propose a modeling framework for policy analysis for value chain improvement. Even though our purpose is more versatile, our research is motivated by the case of olive oil value chain in Turkey. Hence, before problem definition and model formulation stages, we extensively define the problem context in olive oil value chain both in Turkey and in the world. For a brief overview of the corresponding problem context, see Atamer Balkan and Meral (2017). Throughout the chapter, first, the products in focus are detailed, relevant processes in olive oil production are explained, and various stakeholders are listed with their different standpoints. Then, olive oil market both in Turkey and in the world is summarized. In the final part of the chapter, relevant literature on olive oil is provided.

2.1 Products: Olive and Olive Oil

As the products in focus, olive fruits are the main raw materials, and table olives and olive oil are the final products.

Olive Fruit: Olive is a Mediterranean plant cultivated for its fruit which is an important food and source of oil. The olive fruit is a drupe (Figure 2.1). It has a bitter component (oleuropein), a low sugar content (2.6-6%) compared with other drupes (12% or more), and a high oil content (12-30%) depending on the time of year and its variety.

Figure 2.1: Olives

These characteristics make it a fruit that cannot be consumed directly from the tree, hence, it has to undergo a series of processes that differ considerably from region to region and by variety (International Olive Council Website, Online Access: March 2019).

Table Olives: For olives to be consumed as table olives, the fruit is generally treated in sodium or potassium hydroxide, brine or successively rinsed in water, depending on local methods and customs (International Olive Council Website, Online Access: March 2019). Table olives are classified into 3 categories according to the degree of ripeness just before harvesting by the International Olive Council:

- Green olives: Obtained from olives harvested during the ripening cycle when they have reached normal size, but prior to color change.
- Semi-ripe olives: Obtained from olives that are picked when their color starts to change. Harvested before full maturity, when the flesh is quite firm and oil formation has not yet ended.
- Black olives: Harvested when the fruit is close to full ripeness, once it has attained the color and oil content corresponding to each particular variety.

Table olives are processed and marketed depending on their category and local taste preferences.

In our study, we specifically focus on olive oil value chain. Hence, the dynamics in the table olives market are considered to be within our problem boundary but held exogenous.

Olive Oil: In order to obtain olive oil, olives are processed using different technologies, which are detailed in **Processes in Olive Oil Production** section. As by-products of the olive oil extraction process, oil pomace and olive oil mill waste water (OMWW) are obtained (Figure 2.2). Pomace is further processed and used as animal feed or can be re-extracted to have pomace oil. Pomace oil is utilized in cleaners

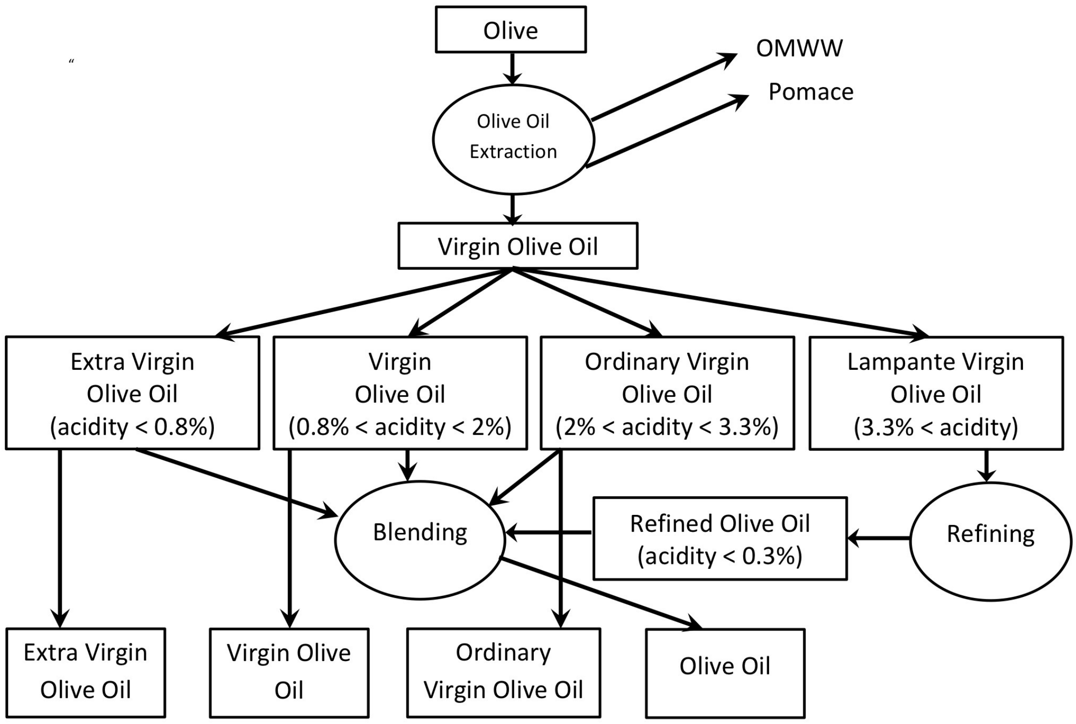

Figure 2.2: Olive Oil Types

(soap, detergent, shampoo etc.) sector. OMWW is considered as a waste that contains high level of organic matter and accepted to be harmful to the environment, especially for water and soil.

According to classification of International Olive Council, olive oil is categorized as follows (Figure 2.2):

1. Virgin Olive Oil: Oil which is obtained from the fruit of the olive tree solely by mechanical or other physical means.
    - Extra Virgin Olive Oil: Acidity less than 0.8% (known as *"Natürel Sızma"* in Turkey).
    - Virgin Olive Oil: Acidity more than 0.8% and less than 2% (known as *"Natürel Birinci"* in Turkey).
    - Ordinary Virgin Olive Oil: Acidity more than 2% and less than 3.3% (known as *"Natürel İkinci"* in Turkey).

- Lampante Virgin Olive Oil: Acidity more than 3.3%, to be refined for use of human consumption or intended for technical use.

2. Refined Olive Oil: Acidity less than 0.3%, obtained by refining virgin olive oils.

3. Olive Oil: Acidity less than 1%, blend of refined olive oils and virgin olive oils (known as *"Riviera"* in Turkey).

2.2 Processes in Olive Oil Production

In this section, relevant processes in olive oil value chain; from olive growing and harvesting to olive oil consumption are detailed. For an overview of processes along the olive oil value chain, see Figure 2.3.

Figure 2.3: Overview of Processes along Olive Oil Value Chain

2.2.1 Olive Growing and Harvesting

Processes in an olive oil value chain start with growing olive trees and harvesting olive fruit, which is the raw material of both olive oil and table olives. Olive growing and harvesting includes the following activities:

- Plantation
- Soil management
- Irrigation
- Pruning, Fertilization and Plant Health Treatments
- Harvesting
- Fruit haulage to the mills

Broadly speaking, there are two main methods of olive tree growing: **Traditional Growing**, generally in mountainous or hilly areas which are not irrigated, and **Modern Growing** which involves irrigation and mechanization. Density for olive grove planting can be classified as Traditional, Intensive, and Super High-Density. For more information, see (Lynch and Rozema, 2013).

The olive fruit starts to develop after olive trees have flowered. Initially olives are green and hard; they first change color to yellow-green and then to reddish purple and finally to black (see Figure 2.4a). Farmers believe that once olives start to fall off the tree, the optimal time for harvesting has already passed and the oil extracted will be of poorer quality.

In general, there are also two methods for Harvesting: **Traditional Harvesting** and **Modern Harvesting**. In the traditional method, ripe fruit from on trees is combed into nets (see Figure 2.4b), or hand picked into baskets; or, unfortunately, olive branches are beaten with sticks and then olives are picked from the ground. Hand picked olives yield the best quality olive oils; whereas harvesting with sticks affects the quality of olive and hence olive oil negatively. In the modern method, mechanical pickers are used. Low-tech mechanical pickers consist of long handled vibrating tongs and they remove the olives from the branches. Nets are spread underneath the trees and olives are collected in nets. High-tech mechanical pickers consist of shaker bars fitted to the back of tractors. They shake the trees from the trunk and unfurls a net around the base of the tree to collect the olives. Mechanization reduces the time between collection and extraction, thus improving the oil quality.

There is a trade-off between olive quality and volume of olive oil, hence farmers have to decide on when to harvest their olives. Premium extra virgin olive oil producers collect their olives early, as the early-harvest olives' oil has low acidity, more fruity aroma and contains more healthy nutrients, but less oil content. However, late-harvest olives have more oil content, hence higher yields, but a milder flavor and less beneficial health attributes (Lynch and Rozema, 2013).

After harvesting, olives are filled into sacks or plastic boxes, and haulaged to olive mills or directly to olive oil producers.

(a) Olives Harvested in Different Colors

(b) Combs Used in Traditional Harvesting

Figure 2.4: Olive Harvesting

2.2.2 Olive Oil Extraction Process

Activities in olive oil extraction process are:

- Fruit reception, classification, cleaning, washing
- Oil extraction
- Storage of bulk olive oil

In order to acquire high quality olive oil, olives must be processed within the shortest possible time after harvesting. Otherwise, as olives wait for long times, fermentation begins, decreasing the olive oil quality. If storing of olives after harvesting is unavoidable, olives are to be stored in stacks of 20-30 centimeters in height in well-ventilated and cool warehouses.

Generally, there are two main methods for olive oil extraction: **Traditional Methods** and **Continuous (Modern) Methods**. In the traditional method, olives are crushed to make an olive paste which is then extruded between pressing mats. In the continuous method, centrifugal force is used for oil extraction. Most common continuous systems are 2-phased and 3-phased systems. Details of flows in olive oil extraction systems can be seen in Figure 2.5 (Souilem et al., 2017). An illustration for olive oil extraction

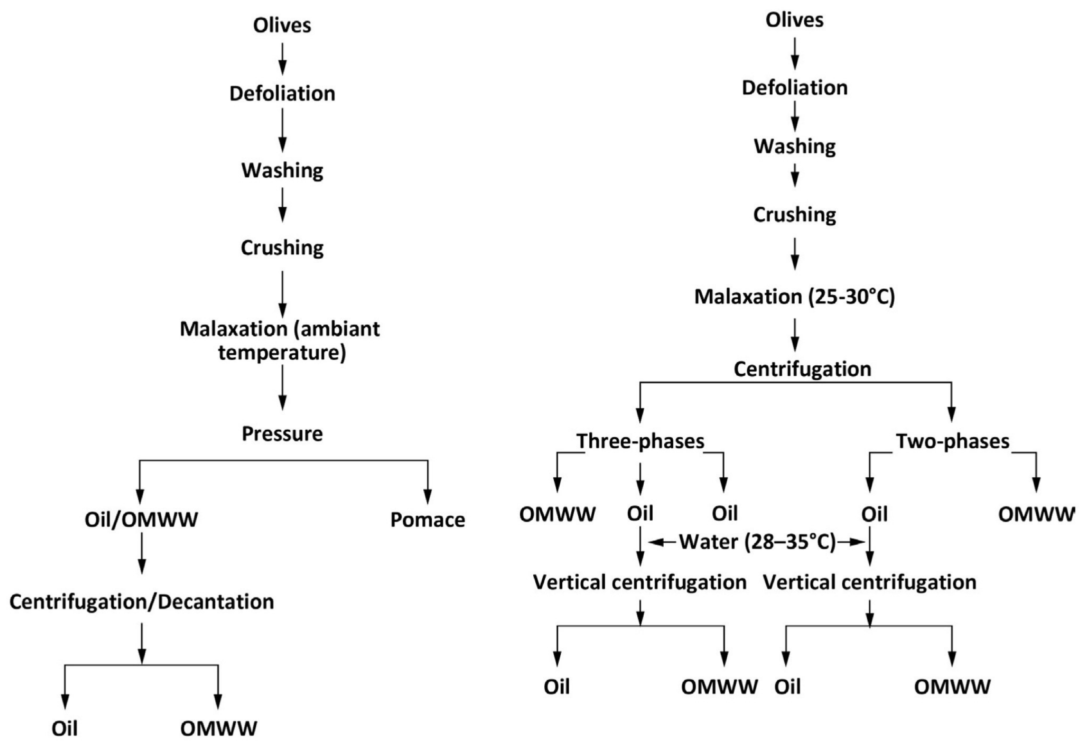

Figure 2.5: Olive Oil Processing Flows, Traditional (left) and Continuous (Modern) (right) Methods (Souilem et al., 2017)

process with the continuous method is given in Figure 2.6 (Wikimedia Commons, 2019).

Olive oil extraction corresponds to a relatively more complicated part of the whole value chain. One of the reasons is that olive oil extraction is done by many different parties via different channels:

- *Small olive oil mills* only focus on extraction process, extract olive oil belonging to different farmers for a certain fee (sometimes for olives or olive oil)
- *Large olive oil producers* focus on obtaining large volumes of olive oil, hence either buy extracted olive oil from from the market, or buy olives as raw material and extract olive oil in their own facilities generally with the continuous methods.

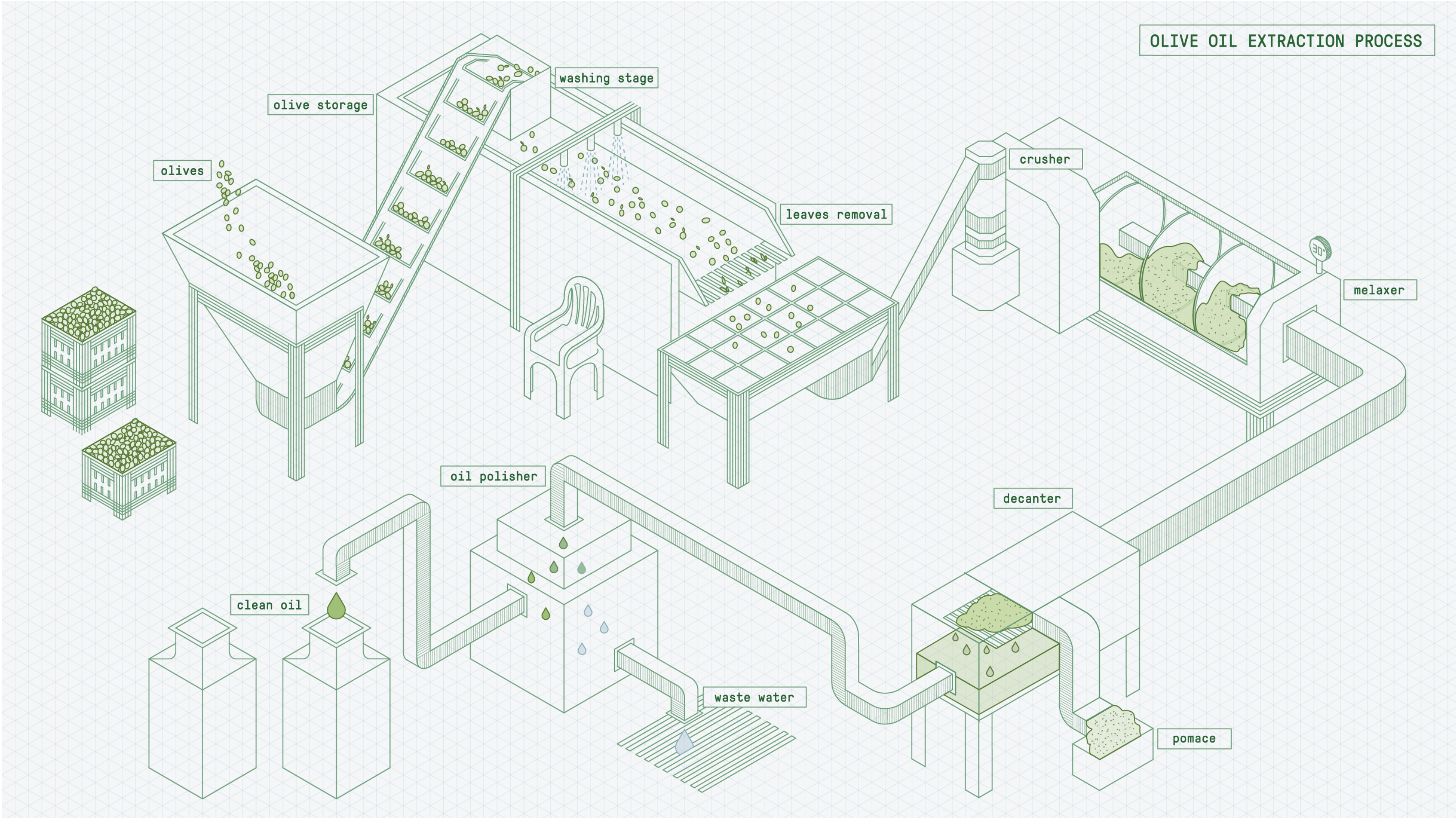

Figure 2.6: An Illustration for Olive Oil Extraction Process (Wikimedia Commons, 2019)

- *Boutique olive oil producers* generally extract oil from their own olives or buy olives from their approved farmers in order to obtain the olive oil at the highest quality. Some of them obtain "monocultivar" (one type of olive variety) olive oils, which have different characteristics for each olive variety.

Extracted olive oil is then analyzed by the unions, olive oil producers or other relevant independent organizations for its physical and chemical properties. Depending on the results of these analyses, olive oil is sent either to packaging facilities or olive oil refineries for further processes.

2.2.3 Olive Oil Packaging, Distribution and Sales

Activities in olive oil packaging plants and refineries are:

- Oil collection logistics (if necessary)
- Refining (if necessary)
- Packaging
- Storage of packaged olive oil
- Transportation to distribution centers

Many industrial olive oil producers have their own packaging plants. Yet, there are still some packaging firms which only perform packaging operations.

Olive oil can be stored broadly in two forms: **bulk olive oil** and **packaged olive oil**. Bulk olive oil is stored generally by the farmers, traders, and olive oil producers. After packaging, packaged olive oil is stored by olive oil producers and sent to several distribution channels.

After the packaged olive oil is directed to relevant distribution channels, namely wholesalers, distributors, retailers etc., the activities performed are more or less standard as for many packaged food products. Reception, storage, transportation and sales activities are done, and olive oil finally reaches the consumers' table.

2.2.4 Olive Oil Consumption

Olive oil meets with consumers at many different levels along the olive oil supply chain: majority of domestic consumers purchase olive oil from the retailers as grocery stores, supermarkets and hypermarkets. Some domestic consumers purchase olive oil directly from farmers or use outlet sales points of olive oil producers and agricultural unions. Being both producers and consumers, farmers use a significant portion of their own olive oil for self consumption.

2.3 World Olive Oil Market

World olive oil production, consumption and trade are mainly done in countries bordering the Mediterranean Sea. More than 95% of olive oil supply and 80% of olive oil consumption are centered in the Mediterranean countries. European Union countries, especially Spain, Italy and Greece, are the three most important players in the world market. World figures between 2008/9 and 2017/18 harvest seasons show that European Union supplies approximately 70% of world olive oil production (International Olive Council Website, World Figures, Online Access: March 2019). Spain (43%), Italy (14%) and Greece (10%) are the three biggest olive oil producers in the world.

Global Production, Global Consumption, Global Trade volumes by countries are summarized in Figures 2.7, 2.8, 2.9 and 2.10.

In global olive oil market, Spain is by far the biggest supplier, followed by Italy and Greece. Tunisia, Turkey and Syria have close production volumes. As it can be observed in Figure 2.7, the first 9 countries produce more than 90% of the world olive oil supply.

As it can be seen in Figure 2.8, participants of global olive oil consumption are not limited with the producer countries. The recent increases in olive oil consumption figures are observed mostly in non-producing countries (Lynch and Rozema, 2013).

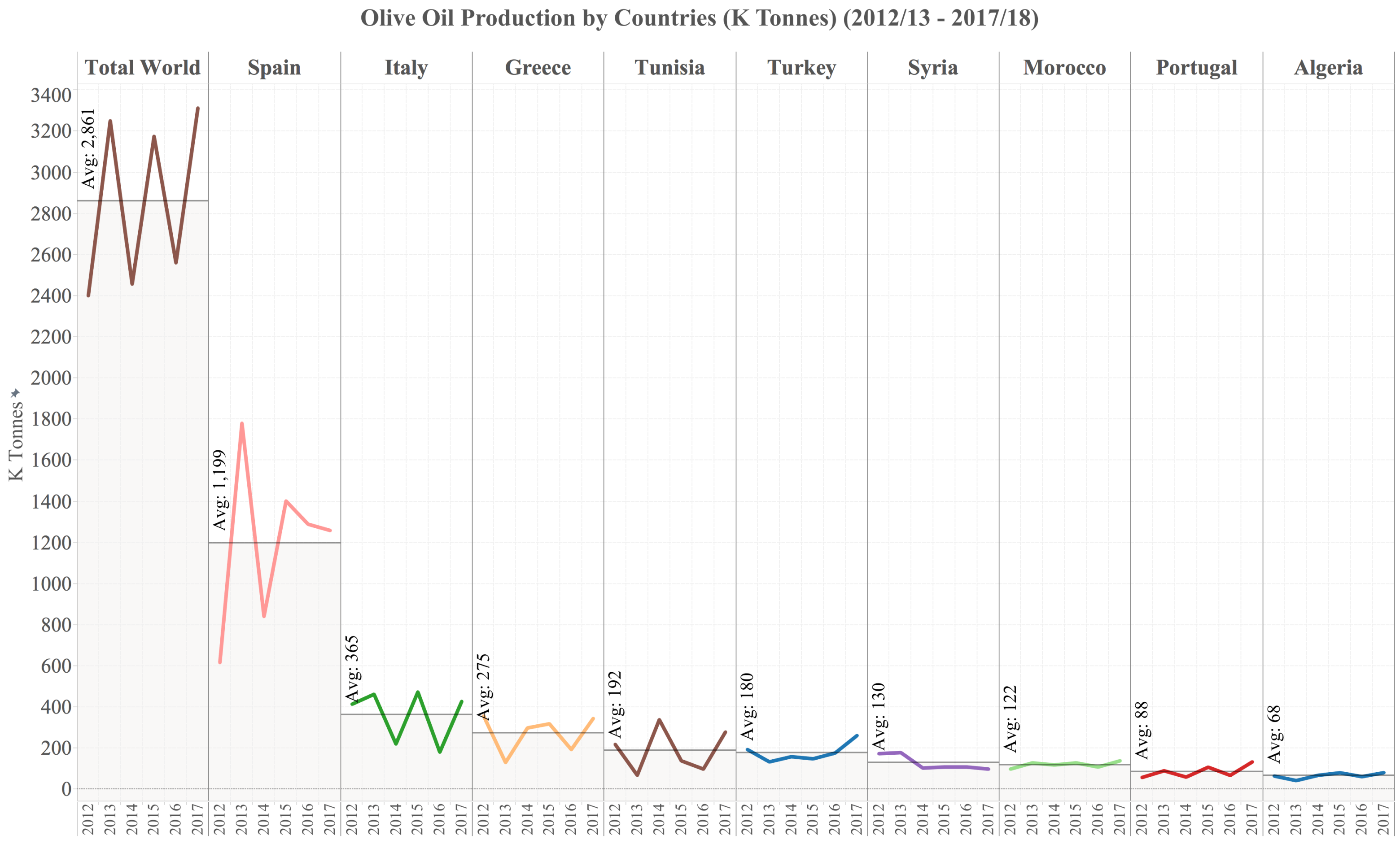

Figure 2.7: Global Olive Oil Production Volumes (2012/13 - 2017/18) (Data Source: IOC Website)

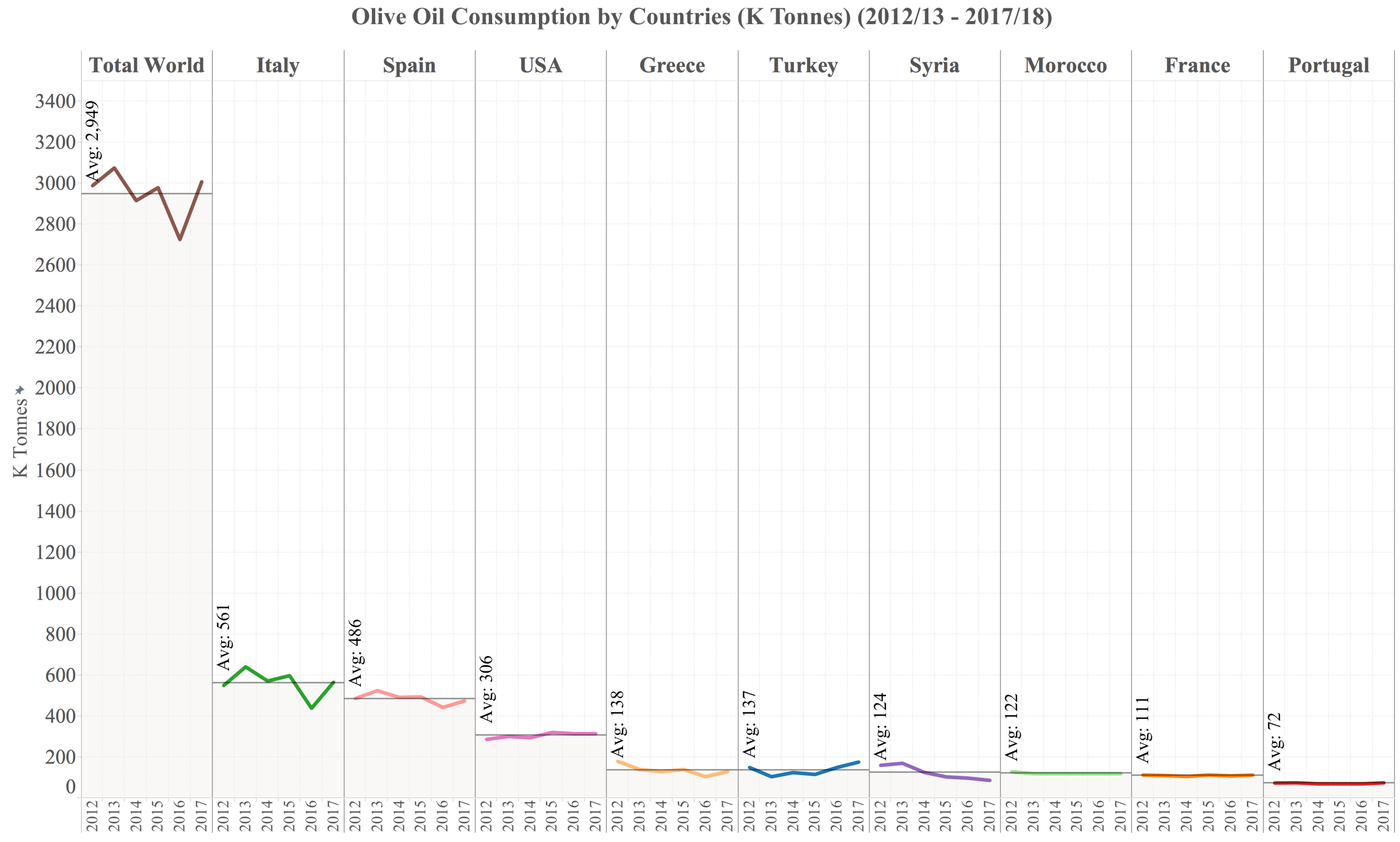

Figure 2.8: Global Olive Oil Consumption Volumes (2012/13 - 2017/18) (Data Source: IOC Website)

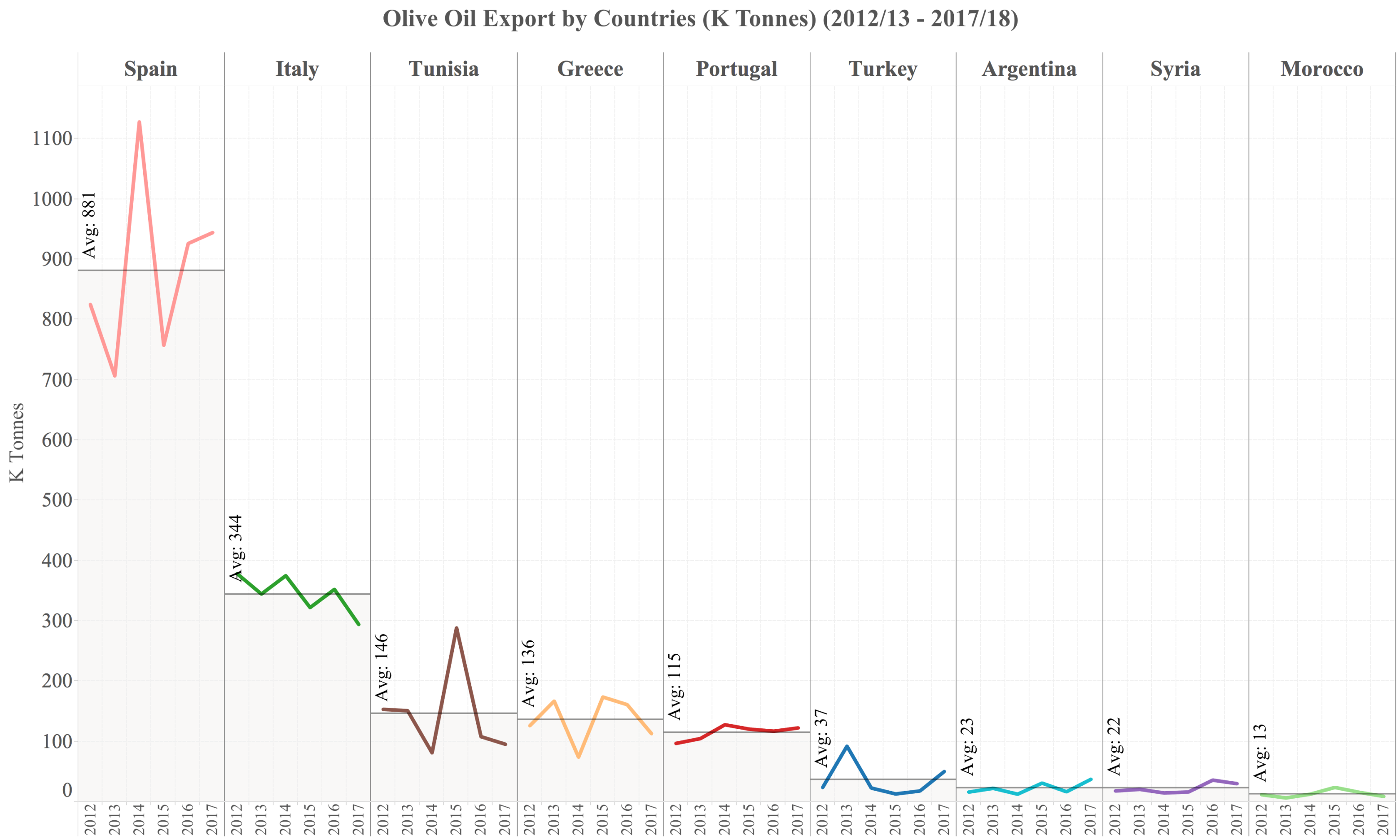

Figure 2.9: Global Olive Oil Export Volumes (2012/13 - 2017/18) (Data Source: IOC Website)

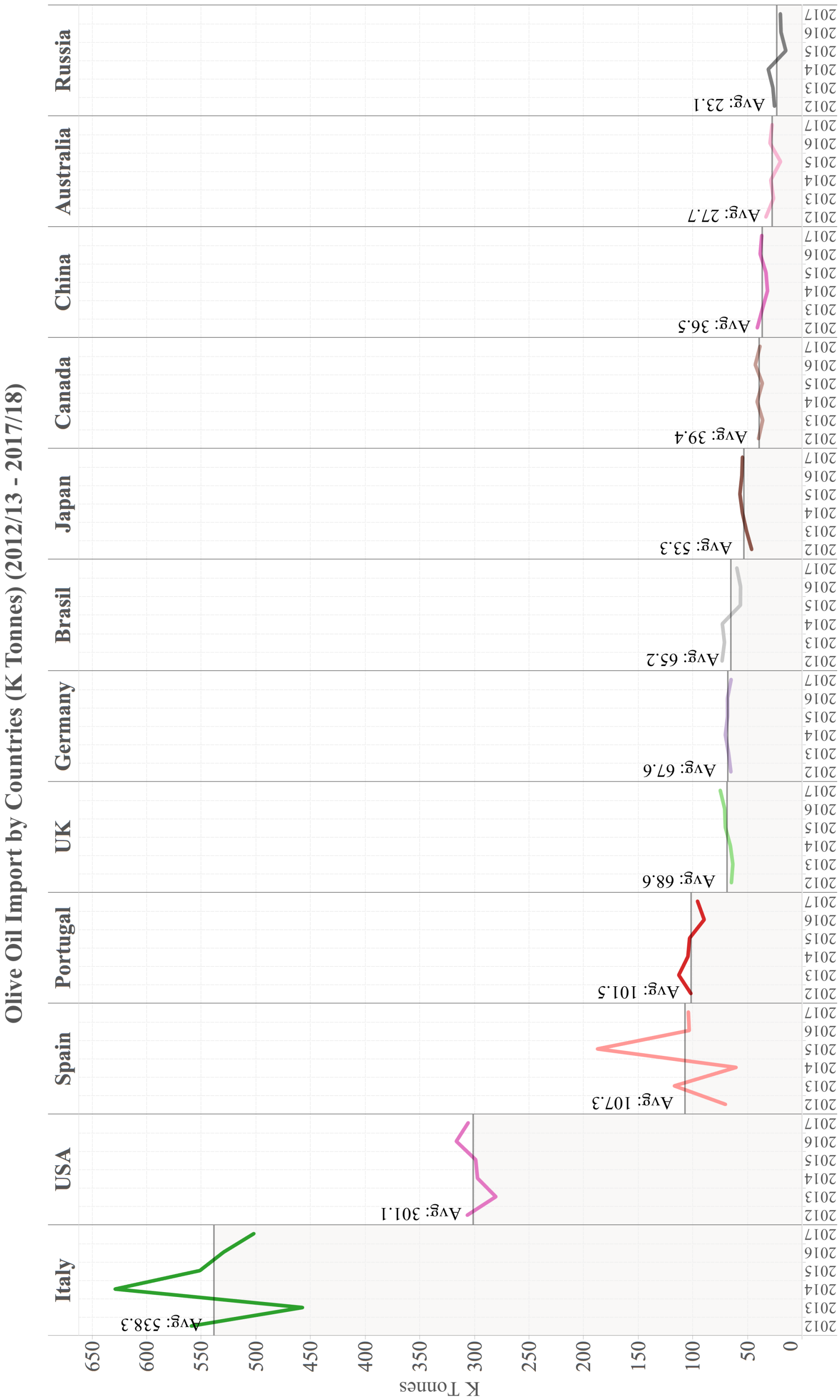

Figure 2.10: Global Olive Oil Import Volumes (2012/13 - 2017/18) (Data Source: IOC Website)

Before getting into detailed data analysis, roles and positions of major players in the global olive oil market are briefly summarized below. This summary is a compilation of our observations based on data analysis conducted with the available data in International Olive Council Website, Country Profiles Reports published by the International Olive Council (IOC, 2012) and Olive Oil Report published by USITC (United States the International Trade Commission) (Lynch and Rozema, 2013).

Spain is the world's largest olive oil producer and exporter; and home to the world's major olive oil bottlers. The country has the world's largest olive-growing area and highest number of olive trees. Spain is one of the price setters in the global olive oil market with its high production volume and relatively low production costs.

Italy is the world's largest olive oil consumer and second largest producer. For many US and European consumers, olive oil is considered to be an "Italian" product and "Italian olive oil" has significantly good reputation in international markets. Italy is home to major blending and packaging facilities operated by multinational companies. Many of these companies import olive oil, mainly from the countries in the Mediterranean region (mostly from Spain, Greece, Tunisia and Turkey), and blend them. After being blended and packaged, olive oil is exported from Italy to consumers all over the world. These multinational companies generally control the olive oil supply chain in Italy; hence, small producers in Italy encounter with difficulties in taking a role in the international market.

Greece is the world's third largest olive oil producer and has the highest per capita olive oil consumption in the world. Two-third of the olive oil produced in Greece is consumed there. Greek olive oil is known for its high quality and flavor; yet only a small portion of the olive oil is traded with "Greek" label in the international market and it is generally exported to European Union countries (mainly to Italy) as "bulk".

Tunisia, **Turkey** and **Syria** and have close production volumes, but their market positions have different characteristics, as explained below.

Tunisia owns one-fifth of the total world olive growing area; it is world's fourth-largest olive oil producer and third-largest exporter. Olive oil sector is important for Tunisian economy; it is the country's largest agricultural source of foreign currency.

Tunisian olive oil is known with its neutral flavor. Hence, it is generally exported as "bulk" to European Union countries for blending purposes. Tunisia benefits from its favorable access to European Union market with a preferential annual import quota granted via EU-Tunisia component of the Euro-Mediterranean Association Agreements. Hence, European Union is a readily available market for Tunisia; and for this reason, Tunisian producers have relatively less incentive to improve their olive oil quality.

Turkey is the fifth largest olive oil producer of the world. The main focus of Turkish olive oil market is domestic consumption. During the twelve years between 2005 and 2017, with the help of government incentives, the number of olive trees has increased by almost 54% and planted acreage has expanded by almost 28% in Turkey. Olive oil production in Turkey continues to increase, providing surplus for increase in export figures. Since olive growing and milling sector has many small producers, participants are not able to benefit from the economies of scale, and Turkey is considered a relatively high-cost producer in the global market.

Syria is the sixth largest olive oil producer of the world, but its role in the global market is now limited and unsteady due to the civil war since 2011.

France and **Portugal** are important olive oil importers and consumers of the European Union,l mostly supplied by Spain and Italy. They are the third and fourth largest olive oil importers, respectively. Portugal also plays an important role in olive oil export while France has low levels of export values.

Germany and **UK** are other important importer countries in EU.

Morocco and **Algeria** are other two top olive oil producer countries from North Africa. Morocco has a production surplus and takes a role (smaller when compared to Tunisia) in olive oil export, while Algeria has a self-feeding olive oil market.

Argentina produces 1% of the global olive oil supply and it is America's top producer and exporter. Domestic consumption is relatively low and Argentina exports most of its production to Brazil, United States and Spain.

U.S. is the top consumer and importer outside of EU. U.S. also invests in olive growing and olive oil production; hence its role as a producer country is expected to expand in the following years.

Outside of the European Union, **Brazil**, **Japan**, **Australia**, **Russia**, **China** and **Canada** are other growing markets in the world.

2.4 Olive Oil in Turkey

Olives are grown in five geographical regions in Turkey, Aegean, Marmara, Mediterranean, South-eastern Anatolia and Black Sea, each with its own distinctive characteristics. Main olive varieties cultivated in Turkey are Ayvalık, Çekişte, Çelebi, Domat, Erkence, Gemlik, İzmir, Memecik, Memeli and Uslu (IOC, 2012).

As seen in Figures 2.7 and 2.9, Turkey is the fifth biggest olive oil supplier with a share of approximately 6% in the world production and 2% in the world exports.

When we consider Table Olives market, Turkey is the second biggest table olive producer in the world with a share of 15%. As for the consumption of table olive, however, Turkey is the world leader. Yet, throughout this study, we focus on olive oil value chain, hence, the dynamics in the table olives market will be considered as exogenous for our modeling purpose.

The statistics on the number of trees and olive fruit harvest can be found in Figure 2.11 and 2.12. The main observation is the increase in both the number of trees and olive harvest volume. In 2005, the number of olive trees was 113 millions (almost 17 million of which were non-bearing) and the yearly average of olive volume harvested in 2004/2005 and 2005/2006 seasons was 1.40 million tonnes. By 2017, there are approximately 175 millions of olive trees in Turkey (almost 26 million of which are non-bearing) and the yearly average of olive volume harvested in 2016/2017 and 2017/2018 seasons is 1.91 million tonnes (TÜİK Database, online access: March 2019). That is, in twelve years, the number of olive trees has increased by 54%, but total olive production has only increased by 36%. Another prominent observation is that, the oscillations in harvest volume among years are significant, especially up to year 2007. This is the so-called "Periodicity (Alternation) Effect (*Var Yılı - Yok Yılı*)" in olive growing. It is also seen that periodicity effect decreases after 2007 but has not yet disappeared.

The olive fruits used for Table Olives and Olive Oil can be seen in Figure 2.12. In Turkey, approximately 75% of the olives collected is processed into Olive Oil, while 25% is processed into Table Olives. One interesting observation in Figure 2.12 is that, the periodicity effect has a more significant influence in Olives for Olive Oil than the influence it has on Table Olives. Table Olive shows a more stationary behavior over time which may indicate that Table Olive has priority over Olives for Olive Oil in the Turkish market.

According to the figures of the last twelve years, approximately 70% of olive oil produced in Turkey is consumed domestically, while the rest 30% is exported. Top olive oil importers for Turkish olive oil are United States of America, Saudi Arabia, Japan, Iraq, Iran and China.

As it is seen in Figure 2.13, domestic consumption of olive oil increases steadily, while production fluctuates due to periodicity and other environmental and climatic effects. Exports do not show a particular trend and changes from one year to another. In international trade of olive oil, Turkey is not a price maker but a price taker. Export volume of Turkey heavily depends on yearly supply level of other producer countries. Hence, export prices and export quantities constitute somehow uncontrollable inputs for the Turkish olive oil market.

2.5 Who is Who?: Stakeholders in Olive Oil Value Chain

In this section, we itemize the essential stakeholder groups along a particular olive oil value chain, especially the olive oil value chain in Turkey. For each stakeholder group, we present critical information in order to understand their position within the chain.

Olive Farmers:

Olive farmers can take part almost in every process along the value chain, yet they are specifically critical for olive tree planting, olive growing and harvesting.

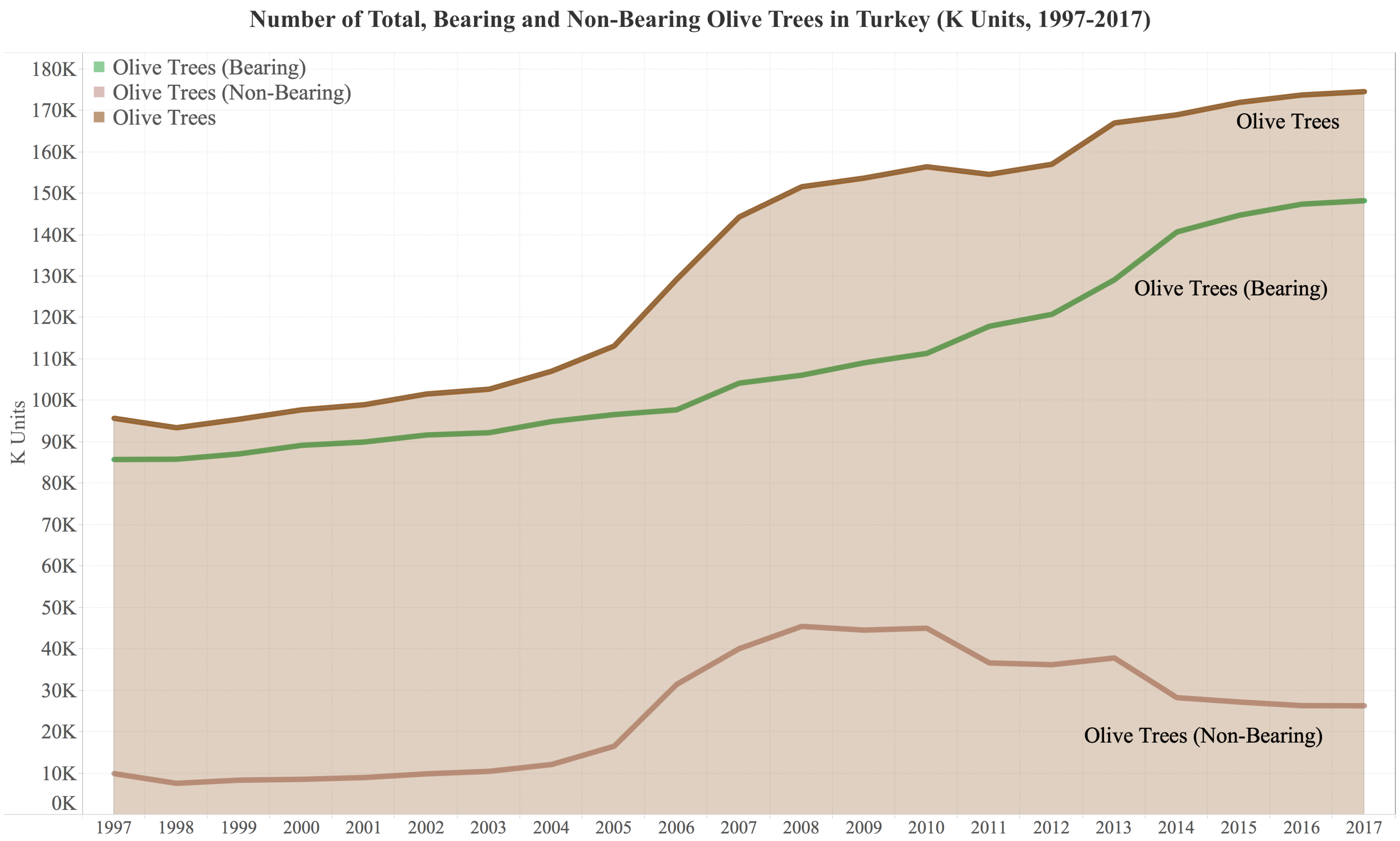

Figure 2.11: Number of Olive Trees in Turkey: Total, Bearing, Non-Bearing (1997 - 2017) (Data Source: TÜİK Database)

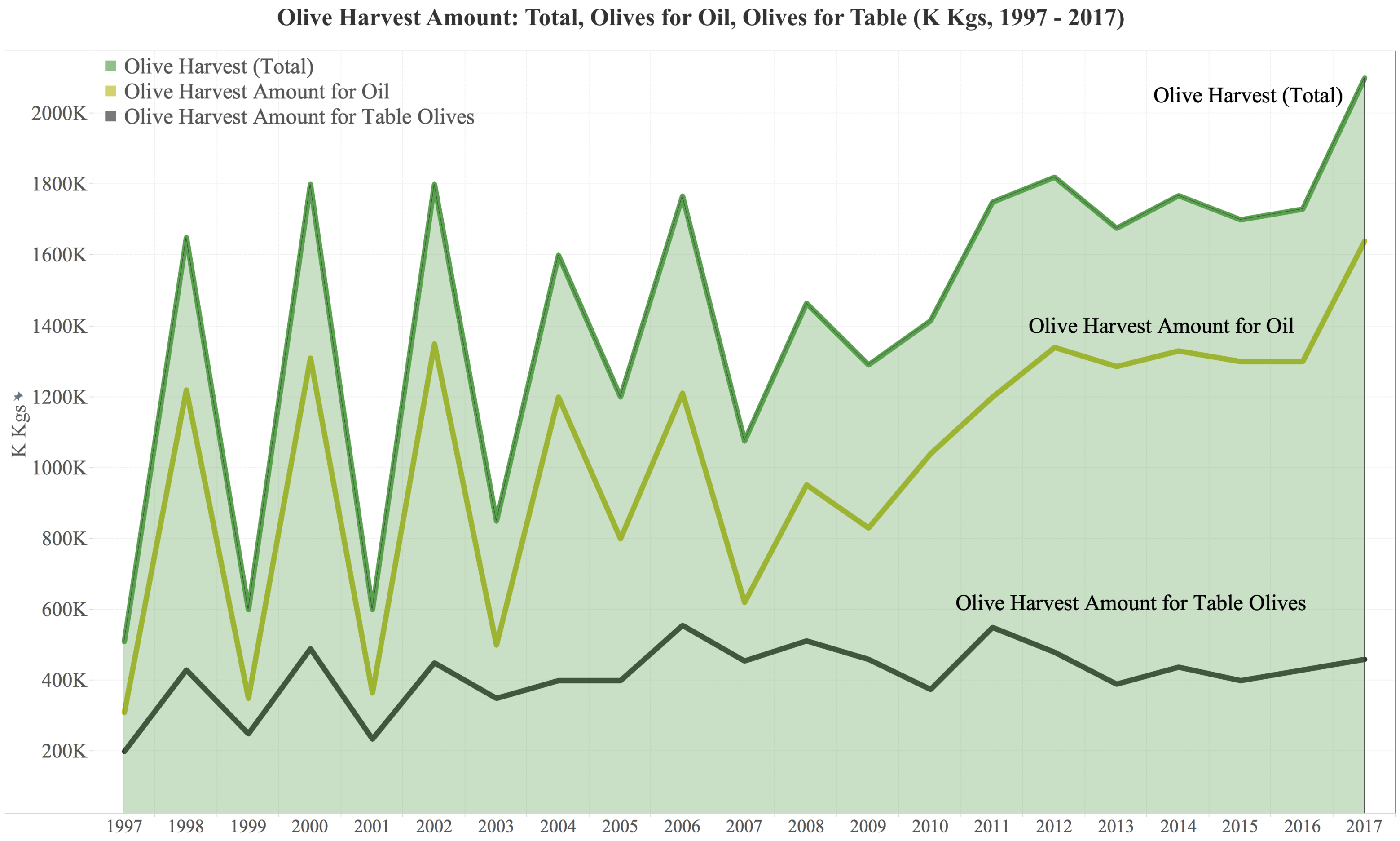

Figure 2.12: Olive Harvest in Turkey: Total, Olives for Olive Oil, Olives for Table Olives (1997 - 2017) (Data Source: TÜİK Database)

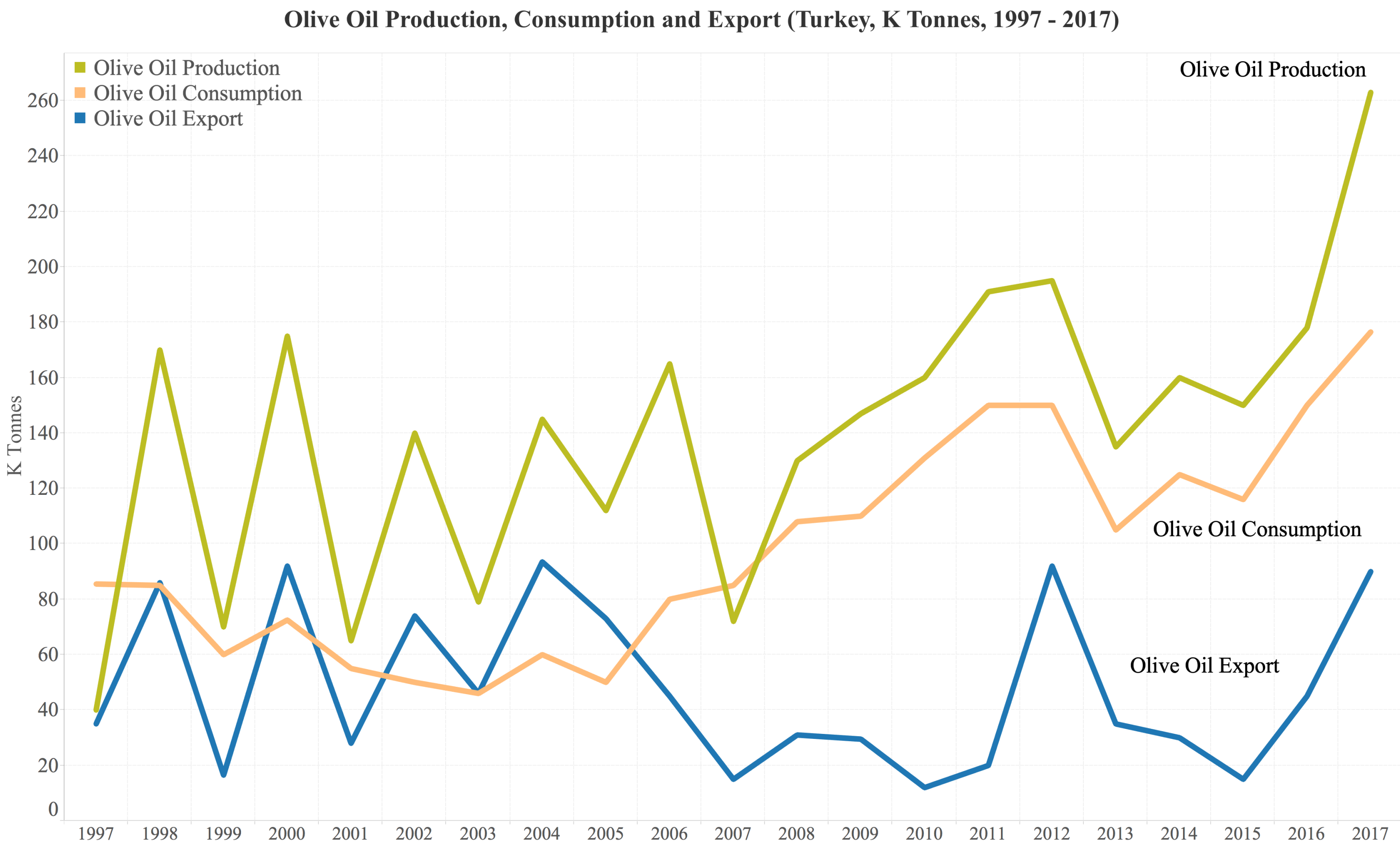

Figure 2.13: Olive Oil Production, Consumption and Export in Turkey (1997 - 2017) (Data Source: IOC Website)

There are approximately 320,000 olive farmer families in Turkey (Ministry of Customs and Trade, 2018). Most of them use traditional farming and harvesting methods without any mechanization.

One critical information for olive farmers is about the financial supports for harvesting. In Turkey, government subsidies and supports are independent of the quality of olives; and depend on the farming area and the olive oil production volume. Hence, a farmer who obtains relatively higher quality of olives is not rewarded more in the current supporting system.

Labor:

Labor is required for almost all activities, but especially critical for harvesting. Olive harvesting is a very labor intensive process as it is explained in **Olive Growing and Harvesting** section. Hand picked olives yield the best quality olive oil; that is, labor cost increases with the olive oil quality. With the traditional growing methods, labor cost is at least half of the production costs. In the European Union, the family work force accounts for 43-57% and paid labor for 10-17% of the total cost of olive growing (European Commission, 2012).

Olive and Olive Oil Cooperatives and Unions:

In Turkey, there are 2 active unions for olive and olive oil (Table 2.1) and these unions consist of a number of cooperatives. Cooperatives purchase both olives and olive oils from farmers. Unions play an important role in the marketing organization with both direct exporting to the international market, and in retailing in domestic market via their regional dealership or their sub-organizations in different regions in Turkey (Tunalıoğlu and Özdoğan, 2008). Unions support farmers by supplying both agricultural inputs and financial credits.

Table 2.1: Olive and Olive Oil Unions in Turkey (The Ministry of Customs and Trade, 2018)

Union	No. of Cooperatives	No. of Members (Farmers)
TARİŞ	31	21,728
Marmarabirlik	8	29,649

According to a recent Turkish Olive and Olive Oil Sector Report (Özaltaş et al., 2016), approximately 20% of farmers sells their products to unions and cooperatives in Turkey. When we look at the case in European Union, the level of cooperative organization is 70% in Spain, 60% in Greece, 30% in Portugal and only 5% in Italy. Nonetheless, even in European Union, these producer organizations are too small to have any weight in the face of industry concentration and the retail chains (European Commission, 2012).

Olive Oil Mills:

Olive oil mills are small firms that have olive oil extraction facilities and offer oil extraction service for farmers. Olive oil mills extract olive oil for a fee (or in exchange of olive oil), and then give back the oil to the farmer. In some cases, mills directly sell the oil to brokers (traders).

Brokers (Traders):

Farmers and olive oil mills sell their olive oil to brokers, considering the market price of the olive oil. Brokers collect olive oil from different farmers and sell them to industrial olive oil producers.

Industrial Olive Oil Producers:

The private industrial olive oil producers' production accounts for 80%-85% of total olive oil production, 80%-90% of domestic sales and 80%-85% of olive oil exporting in Turkey by 2008 (Tunalıoğlu and Özdoğan, 2008).

Industrial olive oil producers in Turkey can be classified under three groups:

- Major Olive Oil Producers (Big Players): Famous brands such as Komili, Kırlangıç, Kristal, have approximately 70% share in the domestic market. They collect both olives and olive oil from farmers and perform extraction, refinement, packaging, distributing and marketing activities.

- Minor Olive Oil Producers (Small Players): Medium size, local olive oil firms, some of which are run as family business. They generally focus on domestic and local market.

- Boutique Olive Oil Producers (Niche Players): Small or medium size companies which focus on product specialization. Their products are generally more expensive than the products of other brands. They aim to take a role in exports as well as domestic market.

Packaging Plants:

Most common olive oil packaging types are glass bottles, plastic bottles, tins and barrels. Some olive oil producers have their own packaging plants and perform packaging operations in their plant. Yet, especially small olive oil producers get packaging service from independent packaging plants.

Wholesalers:

Wholesalers' role in olive oil sector is similar to its role in any other industrial food product. Wholesalers buy olive oil from olive oil producers, unions or packaging firms, and sells them to domestic retailers.

Other Vegetable Oils Markets:

Olive oil has several imperfect substitutes as liquid vegetable oils. Sunflower oil, corn oil, nut oil, soya bean oil and canola oil are major imperfect substitutes of olive oil. According to statistics in 2016, total solid fats and vegetable oil consumption in Turkey is 21.6 kg per year per capita (Onat et al., 2017), whereas olive oil consumption is only 1.5 liters.

Domestic Retailing Points:

In olive oil sales, most common retailers in Turkey are grocery stores, supermarkets and hypermarkets. Olive oil producers have also retailing outlets, especially close to production plants or in the biggest metropolises (İstanbul, Ankara, İzmir etc.); but these retailing outlets would be considered as extended parts of the olive oil producers.

Export Channels and Distributors:

Turkey exports olive oil to more than 50 countries and supplies 2% of world exports. According to statistics between 2008/09 and 2017/18, 73% of olive oil export of

Turkey is in bulk and 27% in packaged form on the average.

Consumers:

Olive oil consumption is relatively low in Turkey compared to other producer countries. In Turkey, yearly olive oil consumption per person is 1.5 liters while it is 12 in Greece, 10 in Spain and Italy, and 6 in Portugal, Tunisia, Syria and Lebanon (The Ministry of Customs and Trade, 2018). The main reasons of low level of consumption in Turkey are high prices of olive oil compared to other vegetable oil alternatives, consumption habits of people and imperfect information on the benefits of olive oil.

Olive oil meets with the domestic consumers via many different channels:
- Farmers extract their olives in order to get olive oil and use a significant portion of oil for self consumption;
- Some domestic consumers prefer to purchase olive oil directly from a farmer that they already know;
- Some of them purchase olive oil from "roadside sales" made by farmers;
- Outlet sales points of unions or olive oil producers give service as retailer points;
- Consumers in urban areas generally purchase olive oil from grocery stores, supermarkets and hypermarkets.

Governmental Institutions:

Ministry of Agriculture and Forestry and Ministry of Trade are the relevant governmental institutions.

Major olive and olive oil producer countries have particular policies and visions. Italy focuses on quality, marketing and branding; whereas Spain focuses on being the biggest producer and controlling the world supply, and Tunisia focuses on bulk exports (Tunalıoğlu and Özdoğan, 2008). However, Turkey does not have a particular policy but has the vision of 'being the second largest olive producer in the world in 2023, following Spain.'

Supporting Industries and Organizations:

Since olive oil is a huge sector, both in Turkey and in the world, there are many supporting industries and organizations.

- International Olive Council
- Turkish National Olive and Olive Oil Council
- Chambers of Agriculture
- Chambers of Commerce and Industry
- Commodity Exchanges
- Exporters unions
- Agricultural input (fertilizers, pesticides, agricultural tool / machinery etc.) producers
- Olive oil extraction equipment producers
- Cleaners (soap, detergent, shampoo etc.) producers as by-product (pomace oil) users
- Universities and research institutes
- Other non-governmental organizations

European Union Countries:

Average olive oil production in the EU in recent years has been 2 million tonnes, representing around 70% of world production. Spain, Italy and Greece account for about 97% of EU olive oil production, with Spain producing approximately 61% of this amount.

In terms of oil quality, in 2009 Spain produced 35% extra virgin oil, 32% virgin oil and 33% lampante oil. The respective figures for Italy in relation to these three categories of oil are 59%, 18% and 24%, respectively (European Commision, 2012).

EU is also the world's biggest consumer.

Other Countries:

Other than EU countries, competitors of Turkey in olive oil production are Tunisia, Syria, Morocco, Australia, Chile and South Africa.

On the demand side, emerging markets other than EU countries are USA, Canada, Japan, Brazil and China.

2.6 Literature on Olive Oil Market

In this section, relevant literature on both world olive oil market and Turkish olive oil market are summarized together with some example studies.

2.6.1 Literature on World Olive Oil Market

Within the scope of review of relevant literature on world olive oil market, we exemplify selected studies which inform us about (1) quantitative modeling approaches to understand olive oil market structures, (2) various type of qualitative and quantitative analysis to understand olive oil industries and markets and (3) business strategies and consumer behavior in olive oil markets. Other relevant topics, specifically "value chain analysis", "system dynamics modeling studies" and " other operations research studies" on olive oil are reviewed in Chapter 4 in detail.

In world olive oil market literature, one important relevant stream of studies focuses on **quantitative modeling of price, supply and demand of olive oil.** These quantitative modeling efforts in olive oil are generally within the research area of econometric analysis based on the past data. These works and their modeling approaches can be exemplified as follows:

Esposti et al. (2002) presents an olive oil model for the Italian market. They utilize the intervention price, the production aid, and the consumption aid as the main policy instruments. They describe three subsystems as "Olive Oil Supply", "Olive Oil Final Demand' and "Olive Oil Price and Stocks Formation". With a set of logarithmic regression equations, they explain the mathematical relationships within and among these subsystems. They utilize a systemic approach: they consider policy influence on the price formation (but the olive oil market price is considered as exogenous), take other oils and fats markets into account and consider self consumption of olive oil by producers. Yet, they model the market as "static" and only focus on determining coefficients of regression equations.

Considering the consumers in Thessaloniki, Greece, Tsakiridou et al. (2006) focus on understanding the effect of consumer attributes (age, gender, education level etc.) on olive oil demand and also estimating the income elasticity for the product. This study delivers a consumption function at the individual level.

Ben Kaabia and Gil (2007) focus on modeling the import demand for virgin olive oil in the Italian market. Import demand model is built with the methodology based on AIDS (Almost Ideal Demand System) and TAIDS (Threshold Almost Ideal Demand System). These models mainly focus on import prices as the main indicator of import demand. The authors also calculate expenditure elasticities and price elasticities of import demand in the Italian market.

Kavallari et al. (2011) identify the factors that determine the olive oil demand in non-producing countries; Germany and UK for their case. They utilize a "gravity" model, which is "based on the idea that the traded volumes from origin i to destination j can be explained by the economic size of the origin and of the destination country and any other forces". They conduct econometric analysis and try to explain olive oil imports in German and UK with these factors: GDP per capita of the importing country, GDP of the importing country, GDP per capita of the exporting country, GDP of the exporting country, Distance, Immigrants, EU-Membership, Mediterranean Partnership, German and/or British tourists to exporting countries, Direct marketing, Labeling, Real Exchange Rate and Dummy variables.

Sabbatini (2014) estimates the supply function of Italian olive oil using the double log transformation. She starts with the analysis by considering production of olive, area of permanent crops in Italy, international price of extra virgin olive oil, price of harvester and thresher import value, plantation stock crops net capital stock, international crude oil price and producer price of olives as variables. After the analysis, she determines that only production of olive, area of permanent crops in Italy and international price of extra virgin olive oil affect the supply of olive oil. She detects a cycle of 5 years in the response of regression, so she uses the date with 5 years of lags.

Xiong et al. (2014) investigate key determinants of the demand for olive oil in the U.S.

olive oil market. They classify different kinds of olive oils by their characteristics (virgin vs. non-virgin), container size (less or larger than 18 kg), and country of export. In order to capture Americans' diet trend in general, they use U.S. monthly import of Italian-style cheese as a reference. As a substitute product of olive oil, they take the U.S. monthly import price of canola oil into account. For the econometric specification of the olive oil demand, they use Almost Ideal Demand System (AIDS). They determine that demand for olive oil is inelastic in U.S. around -0.3 and the own price elasticity of different classifications has a range from -0.4 to -1.4.

Another relevant stream of studies focuses on the **analysis of an olive oil market or industry in various aspects**. These studies can be exemplified as follows:

Flatau et al. (2007) present the olive oil market overview of a non-producing country, Germany. They state that olive oil is perceived as a "healthier" alternative among other edible oils, discuss the demand side and supply side of the market, and give detailed statistics on the trade flow of olive oil in Germany. This study is important for us in showing the increasing market share of olive oil in a non-producing European country.

Coq-Huelva et al. (2012) presents a highly qualitative analysis with focus on Spain, specifically Beas (Huelva) and Arjona–Porcuna (Jaén) and analyzes the olive oil production systems under different quality conventions. The major contribution of this publication to our work is that it enlightens us about the major stakeholders in Spain and their perceptions. In the study, industrial upgrading strategies and quality convention development in cooperatives are examined for two case studies from Spain.

Niklis et al. (2014) present an overview of production, consumption, trade and logistics of olive oil by considering major players in the world market. The study is important to state major difficulties hindering olive oil production, such as consumers' misperceptions on the substitutability of olive oil, high unit cost of production and diseconomies of scale.

Karanikolasa et al. (2018) conduct a conceptual analysis to examine the effects of olive oil producing small farms to regional food systems. They present both qualitative and quantitative analysis results for four representative producing regions, Castellón (Spain), Lucca (Italy), Ileia (Greece) and Central Alentejo (Portugal) with their corresponding food system map representations.

Another relevant stream of studies on olive oil market focuses on business strategies and consumer behavior:

Ward et al. (2003) study the effect of origin of olive oil in German market. They use the data coming from a survey of 926 German households and they build a multinomial logit model to estimate their use of olive oil. They show that consumers do not only differentiate by country-of-origin and also they can be influenced by proactive efforts through the use of various media.

Navarro (2010) presents business strategies in the global olive oil sector. She mentions about different levels of cooperation in the milling stage that is about 70% in Spain, about 50% in Greece and about 15% in Italy. In this work, Turkey is presented with its "special situation" as having a leading cooperative (namely TARİŞ). She mentions that market share of distributor brands increases while market share of manufacturing brands decreases in Spain olive oil market.

Santosa and Guinard (2011) conduct a means-end chains analysis in order to map Northern California consumers' motivations to consume and purchase extra virgin olive oil. They determine attributes, consequences and values that are relevant to consumer behavior and construct a hierarchical value map (HVM).

Imami et al. (2013) analyze Albanian consumer behavior in the olive oil market. They perform the two-step cluster analysis in order to determine the relationship between suppliers and quality perception for the consumers. As the result of the analysis, two clusters named "Happy and Loyal" and "Critical and Quality Seeking" are formed. "Happy and Loyal" consumers consider "knowing the supplier" as the major indicator of quality; they buy olive oil mainly from a single supplier and perceive the quality of olive oil purchased as very high. On the other hand, "Critical and Quality Seeking" consumers consider the label, familiarity with the seller and other quality indicators; their perception of the quality of olive oil purchased varies from lowest to highest level.

2.6.2 Literature on Turkish Olive Oil Market

Within the scope of review of relevant literature on Turkish olive oil market, we exemplify selected studies which focus on (1) general problems in the industry and competitiveness of Turkish olive oil (2) supply chain and value chain structures of olive oil in Turkey, and (3) quantitative approaches to understand the olive oil market in Turkey.

For a comprehensive literature review of studies published between 1988 and 2010 on Turkish olive oil sector, see Seçer and Emeksiz (2012). For another comprehensive review of studies published between 2000 and 2015, see Pehlivan Gürkan (2015). In order to capture the recent advancements in Turkish olive oil sector, two comprehensive and detailed reports, TÜSSİDE (2015) and Özaltaş et al. (2016) can be utilized as guidelines.

In Turkish olive oil market literature, one important relevant stream of studies focuses on general sector problems and competitiveness of the industry, and presents opportunities and recommendations.

Artukoğlu and Olgun (2008) study quality related problems in olive oil mills via conducting surveys with 15 olive oil mills in İzmir. According to their presentation of the olive oil marketing channel, mills collect olives from olive middlemen and olive producers; or they produce their own olives. After the olive oil is extracted in the olive oil mills, olive oil can be sent to agri-sales cooperatives, large-scale producers, medium-sized producers or bulk suppliers. According to the managers of olive oil mills in this sample, the method for transporting olives to the mills and waiting period of olives before processing are two most important factors affecting olive oil quality.

Öztürk et al. (2009) and Özkaya et al. (2010) present comprehensive overviews on problems in olive and olive oil sector in Turkey. They summarize production, consumption, export and import figures of both Turkey and major olive oil supplier countries. They list the major problems of Turkish olive oil sector about olive growing, table olive and olive oil production, olive oil technologies, olive oil consumption, table olive and olive oil trade; and propose solution alternatives and extensive set of recommendations.

Günden et al. (2010) evaluate firm-level competitiveness in the olive oil industry in Turkey. They conduct questionnaires and collect information from a total of 117 firms consisting of olive oil mills, refineries and exporters. Analytical Hierarchy Process is applied to determine factor priorities in both international and domestic competition.

Türkekul et al. (2010) measure the competitiveness of Turkish olive oil among major olive oil exporting countries over the 1990-2006 period. They calculate and compare Revealed Comparative Advantage (RCA), Comparative Export Performance (CEP) and Market Share Index (MSI) values of countries. According to these figures, they form fuzzy clusters of countries, and define differences and similarities between them. They conclude the study with a set of recommendations on the Turkish olive oil market; yet the competitiveness measures and the concluding recommendations are not linked analytically.

Başaran (2011) investigates the problems of small and medium enterprises in Turkish olive oil industry. The author argues that high level of input costs and insufficient level of financial supports are two major problems of the regarding actors. In the final part of the study, she proposes a set of solutions, including restructuring the financial supports and clustering of enterprises.

Özışık and Öztürk (2011) present the position of olive and olive oil sector in Turkey comparing it with major suppliers in the world, Spain, Italy and Greece. They present and compare the recent statistics on olive growing, olive oil and table olives production and consumption. The authors conclude the study with a SWOT Analysis on olive and olive oil sector in Turkey.

Türkekul et al. (2011) summarize the recent statistics on world olive and olive oil production, consumption and trade. Within a global context, they list several opportunities for Turkey in order to be able to expand both the local and global olive and olive oil market. They point out that the growth in olive orchard inventory of Turkey, increase in the number of investors in the sector, growth in foreign markets, increased share of bottled/packaged olive oil exports and increased awareness of "Turkish" brand are the major opportunities for Turkey.

Tunalıoğlu and Özdoğan (2012) discuss the roles of unions, private companies, support aids and quality food safety management systems in Turkey's changing olive oil sector.

Yılmaz (2013) summarizes the agricultural support policies for olive oil in Turkey and in the European Union, and discusses Turkey's compliance with European Union olive oil support policies. She emphasizes the high level of prices in Turkish olive oil market and the requirement of appropriate financial support policies which enable a decrease in prices and an increase in competitiveness of Turkish olive oil in the global market.

Sağlam (2015) analyzes the situation in Turkish olive oil industry with both quantitative and qualitative data, and compares the Turkish case with the cases in European Union and United States. She presents the results of SWOT analysis and Porter's Five Forces of Competitive Position Analysis for Turkish olive oil industry.

Apaydın et al. (2014) focus on problems of olive farmers and conduct surveys with 64 olive farmers in İzmir province. As the most prominent problems, the authors raise "insufficient level of financial supports", "high level of labor cost of harvesting", "insufficient level of irrigation structures", "productivity problems due to periodicity effect". The authors suggest restructuring of financial support policies, investments in irrigation systems and design of educational programs for farmers as possible solutions.

Bayramer et al. (2016) focus on problems of olive oil exporters in Turkey. They conduct semi-structured interviews with 35 actors which take role in olive oil exports and classify the problems identified by the interviewees.

Another stream of studies investigates and presents value chain and/or supply chain structures of Turkish olive oil:

Oktay (2008) briefly summarizes the importance of olive oil for agriculture in Turkey, then presents the components of olive oil supply chain. For one case, the author demonstrates the accumulation of costs along the chain from the farmer to the broker for the domestic market and to the exporter for the foreign market.

In a later and more comprehensive study, Oktay (2010) summarizes the trends both in the world and Turkish olive oil production, and mainly contributes to the literature with detailed definitions and information on stakeholders in the Turkish olive oil supply chain. She also presents a demand forecasting model built on income, residence, family size, marital status, job and education level of households. She bases her study on Household Food Expenditure Statistics published by TÜİK in 2007. She makes recommendations about utilizing supply chain management concepts in order to increase olive oil demand; yet she does not conclude the study with analytical results on olive oil supply chain management.

Azak (2011) and Azak and Tüzün (2012) make value chain analysis for "extra virgin olive oil, packaged in 1-liter bottle" in İzmir province for 2010/2011 crop season. They present the chain formation of the market, and collected cost and price data from 10 olive farms, 15 olive oil mills, 5 packaging plants, 1 cooperative, 5 industrial olive oil plants and 10 retailing points. The cost and price added at the end of each process in this chain are investigated and compared. The most significant result of these studies is that, for the sample analyzed, olive farmers operate with negative profit on the average. In addition to the value chain analysis, Azak (2011) presents an overview of value chain analysis and olive oil value chain studies in the literature.

Tunalıoğlu et al. (2017) conduct value chain analysis for 1 kg of olive oil produced in Aydın province for the harvest seasons 2014/15 and 2015/16. They collect data from 30 actors along the value chain and present relevant costs and prices for each stage. Depending on the value chain analysis results, they argue that wholesale and retail prices of olive oil are found to be higher than expected, when the overall prices along the value chain are considered.

ILO (2018) presents a different perspective on the issue and qualitatively analyzes the Syrian workers' contribution to the olive oil value chain in Gaziantep and Kilis. They present the relevant actors and processes along the chain, and propose suggestions and projects for improvement to create value.

There are a few studies which utilize different quantitative approaches in investigating several issues in Turkish olive oil industry:

Işın and Koçak (2003) make an economic analysis of olive oil plants with different extraction techniques (traditional-hydrated, traditional-dry, continuous), investigating 41 olive oil plants in İzmir. They present physical structures, capital structures and capacity usage/utilization of the plants in this sample. They compare revenues, costs, and profits of plants grouping them according to their olive oil extraction technologies. In the traditional systems, labor cost has the largest share in total cost, whereas in continuous systems, the largest cost component is the depreciation cost. As the result of the analysis, modern continuous systems have higher profitability figures compared to traditional systems.

Olgun et al. (2011) investigate 12 olive oil mills in the Aegean Region of Turkey, and conduct cost and profitability analysis of these plants. In addition to the cost and profitability analyses, they conduct technical efficiency analysis for each of these mills via Data Envelopment Analysis and Stochastic Production Frontier Analysis techniques.

Tunalıoğlu et al. (2013) investigate the effects of real exchange rates on Turkey's extra virgin and refined olive oil. They build two separate models for extra virgin olive oil and refined olive oil based on logarithmic regression. Their independent variables are international olive oil price, Turkish stock exchange olive oil price, real effective exchange rate index and dummy variable representing the global economic crisis in 2008. One important implication of the study is that, an increase in the domestic olive oil price indicates an increase in olive oil exports. This may imply that, in Turkey, the main focus is on the domestic market, and that the olive oil export quantity depends on the excess supply.

Çarıkçı (2015) determines target international markets for Turkish olive oil with multi-criteria decision making techniques. He first presents data and trends in both global and domestic olive oil production, consumption and trade. He then determines appropriate criteria, weighs them via Analytical Hierarchy Process, rank target countries accordingly, and gathers feedback about the results from 20 olive oil firms. According to the results of the analysis, appropriate target markets are countries from Central Asia, Middle East and North America.

The existing literature on Turkish olive oil value chain problems follow both qualitative and quantitative approaches. In quantitative approaches, the authors generally analyze historical data and make suggestions and recommendations based on their implications. In our study, we aim at providing a modeling framework for policy makers which can provide quantitative economical outcomes of the candidate future interventions for value chain improvement.

CHAPTER 3

PROBLEM DEFINITION, MODELING PURPOSE AND DYNAMIC HYPOTHESIS

In this chapter, the problem in focus, our modeling purpose and the dynamic hypothesis are defined. The main guideline used for the content of this chapter is "Steps of the system dynamics method" section of Barlas (2002).

Global agricultural commodity and food price fluctuations, especially for developing countries, is a major concern for policy makers all over the world. Increasing volatility and uncertainty in agricultural commodity and food prices have received substantial attention after peaking in prices during 2007-2008 and later in 2011 (FAO, 2017). Additionally, several global trends (i.e. increasing world population and food demand accordingly, changing dietary transition towards higher consumption of meat, fruits and vegetables, relative to that of cereals) have been adversely affecting food security, poverty and the overall sustainability of food and agricultural systems (FAO, 2017).

Sustainability and value chain development are strongly interrelated. A "value chain" in agriculture identifies the set of actors and activities that bring a basic agricultural product from production in the field to final consumption, where value is added to the product at each stage (Bolzani et al., 2010). In order to make the best of globalization and attain sustainable growth, we need to understand the dynamic factors within the whole chain (Kaplinsky and Morris, 2002).

In Turkey, stakeholders along the agricultural value chains also encounter with unforeseen fluctuations and increases in agricultural commodity prices. One prominent case of these phenomena has been observed in olive oil value chain in Turkey. In recent years, despite the increasing population of olive trees and olive oil supply (see

Chapter 2.4 Olive Oil in Turkey for details), consumer prices for olive oil have unexpectedly increased. In Figure 3.1, you can find three different price levels along the olive oil value chain in real terms: raw olive fruit price (agricultural, ex-farm price), processed bulk olive oil price (ex-processing facility price) and packaged olive oil retail price in Turkey between years 2007 and 2017.

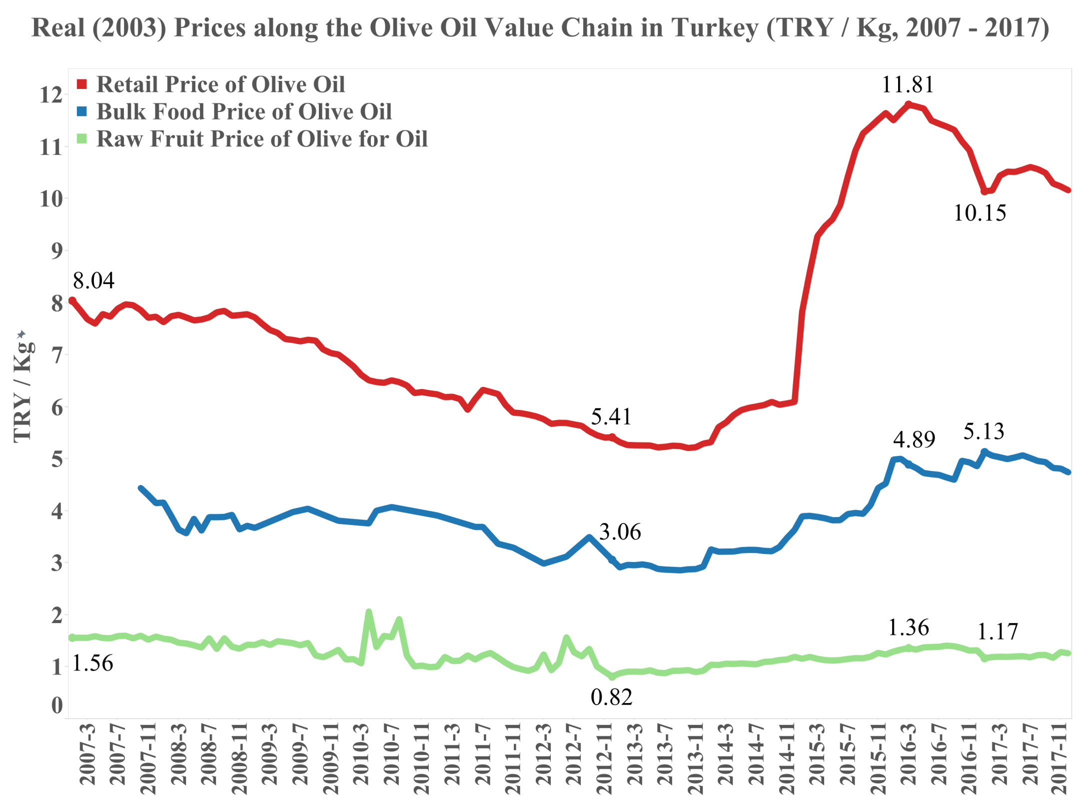

Figure 3.1: Real Prices along the Olive Oil Value Chain in Turkey, Turkish Lira/Kg, 2007 - 2017 (Data Source: TÜİK Database)

The reference dynamic behavior observed in prices in Figure 3.1 can be summarized as follows: Olive Fruit Price has a decreasing trend with some fluctuations from 2007 to the end of 2011, and then follows an increasing trend to the end of 2017. Bulk Olive Oil has a similar behavior to Fruit Price, it has a decreasing trend between 2007-2011 and an increasing trend between 2012-2017. Especially between 2012 to the end of 2015, it follows stepwise increases from one year to the other. The most interesting dynamic behavior is observed in olive oil retail price: a decreasing trend to the end of 2013, then a small negative exponential growth to the end of 2014, then a remarkable growth-and-decline to the end of 2016, then a much smaller growth-and-decline to the end of 2017.

The implications about the relationships among the price levels depending on the observations in Figure 3.1 and relevant quantitative analysis can be summarized as follows:

- The relationships among the price levels are not linear; one price level can not be explained as a linear function of another.
- Although price levels exhibit different trends, their behaviors apparently affect each other with a time delay.
- Even though one can consider that fruit price and bulk food price act as the material cost and adjust the retail price level, surprisingly, the sharp increase in retail price comes first, and then it affects the prices in lower levels of the value chain.
- Price levels affect each other in both directions along the agricultural value chain: i.e. retail price affects the bulk food price and then bulk food price affects the retail price, hence there exist feedback loops among prices.

While these price behaviors are observed along olive oil value chain in Turkey, the story in other stages of the chain can be summarized as follows: with the effect of government supports for olive tree planting, olive tree stocks of Turkey have increased by 54% during the previous two decades. The rise in the population of trees has naturally increased olive harvest volume by 36% and olive oil production amount by 42% within the same time horizon. These increases bring about higher expectations for a growing olive and olive oil industry. Depending on their price expectations within a harvest year, stakeholders who are able to keep inventories (i.e. farmers, producers, traders/brokers, etc.) store the olive oil as “bulk” and use the power of speculative inventories. As a result, they give rise to oscillations in prices. Additionally, when compared to the other olive oil producer countries, stakeholders in Turkey face with low “fruits per tree” values, and hence with higher unit costs, which also leads to increases in prices. On the export side, since Turkey is not a price maker but a price taker in the world market, export prices are mainly determined depending on the world prices. When there is a shortage of world supply, export prices naturally increase and act as a new benchmark for the prices in the domestic market. For instance, starting from early 2013 to late 2015, unit export price of olive oil for Turkey has increased by almost 80% in US Dollars and then in less than one year, it has dropped by 40% (Data Source: TÜİK Database.) These types of shocks are exogenous effects but trigger the domestic market prices.

The dynamic behaviors observed in Figure 3.1 and initial quantitative analysis indicate that prices along the olive oil value chain are sensitive to both external effects and behavior of each other as internal effects. Hence, the expected behavior of the prices in the near future is variant: one alternative is that they have already completed their growth-and-decline cycles and they are stabilized at their new levels as their behavior during 2017 indicates. Another alternative is that decline part of this cycle has not yet been completed, the value chain would not resist the high level of retail prices, and would decline and reach to lower levels. Still another alternative is that another remarkable growth-and-decline cycle may arise and the prices may even reach to higher levels.

Stakeholders in the industry point out that, if consumer prices are sustained in higher levels, more and more consumers may eventually switch their preferences in the favor of "other vegetable oils", and as a result, olive oil demand may decrease. They worry about the fact that, in the near future, there will be a high level of excess olive oil supply, prices will dramatically go down and hence the economical sustainability of the olive oil industry in Turkey will be in question.

Higgins et al. (2010) point out that the previous applications of OR in agriculture focus on decomposing the problem into components and then identifying the optimal solution for each component, however, this approach has limitations in agricultural value chains which include complex interacting elements. They demonstrate the agricultural value chain analysis applications of complex system science methods, namely, agent-based modeling, system dynamics and network analysis, in order to gain insights under different and dynamic conditions.

In this study, in order to understand the complex dynamics along the agricultural value chains and provide a quantitative analysis for olive oil value chain in Turkey, we utilize system dynamics modeling which is one of the complex system science methods as Higgins et al. (2010) recommend.

Considering the dynamic problem situation summarized above, we have two major **modeling purposes**:

- to understand the price, supply and demand dynamics along the agricultural commodity value chains and to explain them analytically and mathematically via a system dynamics model,
- to make policy and scenario analyses for the specific case of olive oil value chain in Turkey with the focus of economical sustainability.

For **the time horizon** of the problem, years between 2007-2023 are selected. In Figure 2.11 in Chapter 2, we observe that the effect of periodicity is significantly different before and after 2007. This difference effects the behavior of the whole chain since olive trees are the main sources of raw material. Hence, year 2007 is selected as the starting year of the time horizon. In scenario and policy analyses, the current time is considered as the end of 2018, and the near future considered is five-harvest-years-long, which consist of years 2019, 2020, 2021, 2022 and 2023. That is, time horizon of the model is set to 2007-2023.

Dynamic models can be continuous or discrete in time. In time-continuous models, change can occur at any instant in time, whereas in time-discrete models, change can only occur at predefined discrete points in time (Barlas, 2002). Real dynamic systems consist of both types of dynamics. When we consider the case in olive oil industry, we can see that olive harvest occurs only once in a year as a time-discrete event, but olive oil consumption continues all through the year. In such a model, we should select the time unit of the model small enough compared to the time horizon of interest.

For **the time unit** of the problem, "month" is selected. Most of the available data on Turkish olive oil value chain (tree stock levels, harvest amount, olive oil production, olive oil consumption, etc.) are unfortunately annually reported. Yet, system dynamics modeling is a behavior pattern-based approach and we aim to understand the behavior of different price levels along the chain. The most appropriate time unit to capture the behavior of the prices is determined as "months". It is an important convenience for us that olive fruit price, bulk olive oil price and olive oil retail price data are reported monthly. Even if these data are not available monthly, the time unit of the problem is still to be set as “months” and the reference historical data are to be anticipated by the modeler.

By means of the quantitative analysis of dynamic data, information gathered from relevant stakeholders and the theory in relevant literature, a high level causal loop diagram is constructed as seen in Figure 3.2.

We summarize the relationships in the causal loop diagram as follows:

- Olive Trees → Olive Harvest → Olive Oil Processing → Bulk Olive Oil Inventory → Olive Oil Packaging → Packaged Olive Oil Inventory (i.e. availability of olive oil) → Olive Oil Consumption constitutes a positively related chain.
- Olive Trees, Olive Harvest, Olive Oil Processing and Olive Oil Packaging decrease with relevant cost figures and increase with their regarding price levels along the chain.
- Bulk Olive Oil Inventory and Packaged Olive Oil Inventory increase with their corresponding olive oil supply flows and decrease with domestic consumption and export.
- Olive Oil Consumption is determined by Olive Oil Retail Price and many other external factors (such as population, income, substitute product prices, etc.).
- Prices are positively related with the relevant cost figures and negatively related with their corresponding supply counterparts: there exist negative feedback loops between Olive Harvest → Olive Fruit Price → Olive Harvest, Olive Oil Processing → Bulk Olive Oil Inventory → Bulk Olive Oil Price → Olive Oil Processing and Olive Oil Packaging → Packaged Olive Oil Inventory → Olive Oil Retail Price → Olive Oil Packaging.
- Additionally, as observed in Figure 3.1, price levels affect each other in both directions: there exists positive feedback loops among consecutive price levels along the chain.

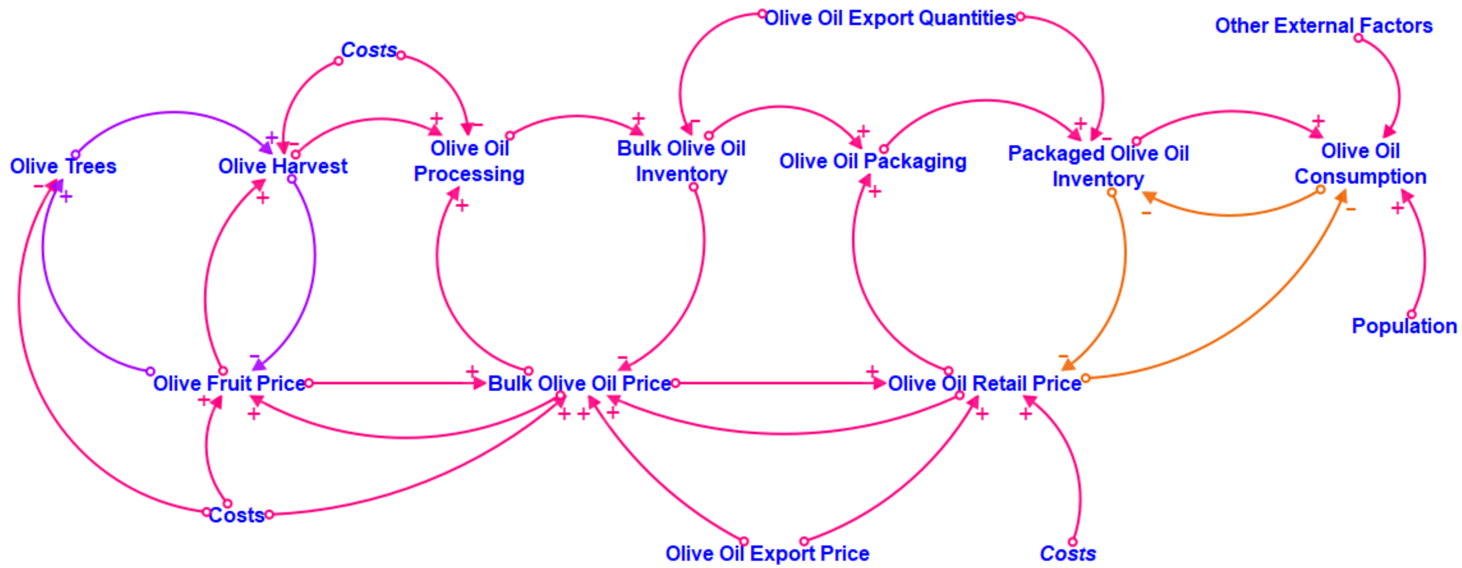

Figure 3.2: High Level Causal Loop Diagram for the Turkish Olive Oil Value Chain Model

- Since a portion of olive oil is exported, olive oil export prices affect both bulk olive oil price and olive oil retail price.

Depending on the characteristics of the problem; olive trees, olive oil inventories and different price levels are anticipated to be the main "stocks", and harvest, processing, packaging and consumption variables are anticipated to be the main "flows" of the formal model. Depending on the structural and analytical requirements, other stocks and flows are also added to the formulation. For definitions of stocks and flows in system dynamics modeling, one can refer to Appendix A.

Our **dynamic hypothesis** is that different price levels along the agricultural value chains (i.e. raw fruit / plant price, processed bulk food price, packaged food retail price etc.) are not the sole summation of the relevant costs and profit margins. When one price level encounters with an external effect, such as a policy decision in governmental financial supports or a change in world market conditions, other price levels along the value chain are affected in a nonlinear manner. These changes may lead to abrupt and unexpected increases or decreases in other price levels due to their endogenous structures and embedded feedback loops. These endogenous structures can be exemplified as food stock levels, stakeholders' perceptions on price expectations or desired supply quantities. Even when the corresponding external effect diminishes, stabilization of prices may take too long and damages value chain actors. Some possible results of these behaviors are usually observed as unexpected gaps between agricultural supply and demand, and also financial loss of stakeholders along the corresponding agricultural value chain.

Although we are inspired by olive and olive oil value chain in Turkey, this problem is valid for several agricultural commodities which have the following characteristics: the raw fruits are harvested at specific times of the year and they are perishable when harvested, then they go through some processes and become bulk food which is storable. The commodity couples which have similar characteristics can be exemplified as fresh vegetables - vegetable oils, citrus - juice and fresh nuts - dried nuts. In terms of our problem setting, they take part in country's exports but the country is a price taker, not a price maker in the world market. Their short term supply is sufficient for their domestic demand and their long term supply shows an increasing trend. Yet, contradictorily, their prices in the domestic market may also be increasing. Additionally, the gap between prices along the value chains can not be explained in linear terms and is more than the profit margins among the value chain partners.

Before presenting the formal model structure in Chapter 5, we provide a summary of the related literature in Chapter 4.

CHAPTER 4

LITERATURE REVIEW

In this chapter, we provide a summary of the related literature review in three groups: first, we start with the value chain concept and summarize a set of selected studies in agricultural value chain development. Then, we present an overview of operational research studies that focus on problems in food, agriculture and value chain area. As the major part of the chapter, we provide review of relevant system dynamics modeling studies and summarize our contribution to the existing literature.

4.1 Value Chain Framework and Olive Oil Value Chain Analysis

The term **“value chain”** is first used by Michael Porter at the firm level. The concept and importance of “value added” activities are emphasized in Porter (1980) and the term “value chain” is explicitly defined in Porter (1985) as “the collection of activities that are performed to design, produce, market, deliver and support the product”. In time, the term has been adapted to industry-level and global level value chains. A broader and updated definition of the value chain can be stated as “the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use” (Kaplinsky and Morris, 2002). In the agricultural context that we focus on, **agricultural value chains** “identifies the set of actors and activities that bring a basic agricultural product from production in the field to final consumption, where at each stage value is added to the product” (Bolzani et al., 2010).

In order to make the best of globalization, and hence entering into global market powerfully for a sustainable growth, we need to understand the dynamic factors within the whole chain (Kaplinsky and Morris, 2002). As a key framework, value chain perspective guides us in understanding the processes; how inputs and services are brought together and used to grow, transform, and produce a product; how the product moves physically from producer to customer; and how the "value" increases along the chain (Webber and Labaste, 2010).

In recent years, many governmental and non-governmental organizations deal with **value chain concepts**, conduct value chain development projects in several countries of the world and issue several publications. Many of these publications are guidelines for value chain development; they include general principles on value chain framework with examples from real life cases. For a comprehensive review of these guidelines with a brief history of value chain concepts, see Nang'ole et al. (2011). For comparative reviews of selected guidelines, see Donovan et al. (2013) and Donovan et al. (2015). As a fundamental reference, Kaplinsky and Morris (2002) provide a comprehensive handbook for the value chain research with concrete guidelines and tools, which guide us in understanding general value chain concepts.

In a more focused context, there are also several publications which constitute guidelines for **agricultural value chain development**. A selection of these guidelines can be listed as follows: Humphrey and Memedovic (2006) discuss global value chains in the agrifood sector and state that "agricultural growth is central to poverty reduction". Da Silva and Souza Filho (2007) propose a methodological guideline for the analysis of agrifood value chains. They provide a step-by-step guideline starting from research organization and data collection to value chain intervention and results validation. Within the scope of "Making Markets Work Better for the Poor" project, M4P (2008) presents a comprehensive guideline for the value chain analysis with definitions and a broad set of qualitative and quantitative tools. Webber and Labaste (2010) propose a set of tools for the value chain development projects and present case studies from agricultural industries in Africa. Trienekens (2011) presents a framework for value chain analysis in developing countries which consists of three components: identification of constraints for the value chain upgrading, definition of the value chain structure, identification of the value chain upgrading opportunities. Miller (2011) explains the concept of value chain finance and gives a set of concrete recommendations for agricultural value chain finance strategy and design.

From a point of view different from the agricultural value chain development studies summarized above, Archer et al. (2009) emphasize that agricultural chains are subject to managerial, social and biophysical complexity. In order to facilitate the implementation of adaptation strategies that add value, they propose to use a complexity matrix of biophysical and management factors. Depending on the agricultural chain complexity; prediction, operation, optimization or innovation based strategies are proposed. In line with a similar perspective, Rich et al. (2009) remark the complexities in value chains and discuss the existing approaches in value chain analysis and development. They emphasize the requirement of a broader use of quantitative approaches and highlight the appropriateness of system dynamics and agent based modeling approaches in value chain intervention assessments.

Among the publications on agricultural value chain development, some of them specifically focus on **the value chain of a specific product in a country**. These reports and publications about agricultural value chain development cases can be exemplified as follows: Lecraw et al. (2005) summarize the value chain analysis conducted for the Mongolian cashmere industry. Panlibuton and Lusby (2006) summarize the value chain study conducted for the Indonesian cocoa beans. Cromme et al. (2010) first investigate the situation in potato value chains in different producer regions of the world, then propose improvement mechanisms and recommendations for both producers and policy-makers. Chagomoka et al. (2014) conduct value chain analysis of traditional vegetables from Malawi and Mozambique; they identify value chain actors, describe relationships among them and provide a quantitative analysis on their income distribution. They conclude the study with a SWOT analysis and a set of recommendations. Neilson et al. (2015) examine the state of the Indonesian coffee value chain and proposes value chain upgrading recommendations. Heery et al. (2016) analyze dairy and beef value chains in Ireland with a global value chain methodology. Antonio and Griffith (2017) conduct value chain analysis for cashew value chain in Mozambique; they present a value chain map, SWOT analysis, performance indicators of the value chain and conclude their study with the case of a private food company in Mozambique. Kilelu et al. (2017) focus on small holder integration into agri-food markets and conduct a rather qualitative and structure-oriented value chain analysis for the case of dairy value chain in Tanzania. Tröger et al. (2018) emphasize the complexity of agricultural value chains and the requirement of a systemic understanding, and examine the case of the fresh pineapple value chain in Uganda. They follow systems learning approach and participatory methods in order to capture the value chain structure and value chain actors' perspectives. Vicol et al. (2018) consider the specialty coffee value chain in Indonesia and discuss the upgrading opportunities with value chain interventions. These studies are only some selected examples from a vast amount of studies each of which presents value chain analysis of a specific product in a country. The common feature of these publications is that most of them have similar structures: they introduce the value chain structure and actors with appropriate tools, present the results of relevant qualitative and quantitative analysis, and conclude the study with a set of value chain intervention recommendations. The methods they use are able to assess the current condition of the value chain, but are not able to assess the impacts of alternative interventions.

Some of the agricultural value chain analysis and development studies specifically focus on **olive oil value chains**. These studies and their approaches can be exemplified as follows: Leonetti et al. (2009) investigate Albanian olive and olive oil value chain and present the market and industry structure in Albania in a detailed report. They present cost, price and profit margin data for different types of producers, processes and products. They also present the role of government and subsidies given to the olive oil industry in detail. Additionally, they discuss consumer preferences. As the concluding remark, they present a SWOT analysis and recommend the ways of improvement. The important part of this report to us is that they state that Albanian producers suffer from low productivity per tree and the high oscillation of yields from one year to another. These factors lead to high production costs and they have concerns about the economical sustainability of the industry in Albania.

In a study carried out by the Olive Oil Agency of Spain, Lain (2010) prepares a quantitative value chain analysis for both extra virgin olive oil and (regular) olive oil separately for the Spain case. They define olive oil value chain consisting of three major processes (stages): olive growing, olive oil processing and olive oil distribution. By data collection and interviews in Spain, they calculate and present cost of each stage and market price of the output at the end of each stage. Hence, in a way, they present how much economical value is added at each stage and how much value is gained by the stakeholders who perform the activities in that stage. The study is very important for us because it gives an indicator for the economical sustainability of the olive oil industry in Spain. It is also so important in showing us that the highest cost along the value chain is paid by the farmers during the olive growing stage. Mili (2010) gives an overview of the international olive oil market and proposes some solutions for the challenges that are faced. This study is important in stating that along the olive oil value chain, there is a power shift from producers to distributors and that bigger markups exist in the final stages of the value chain. Navarro (2010) makes a qualitative analysis on impacts of economic crisis on food markets, especially on olive oil and table olives value chain. This study is important for us in two aspects: first, the author states that during the economic crisis periods and as a response to increasing costs, farmers face with the pressure on producer prices. The second important point is that the author implicitly calls for holistic approaches in value chain development studies and also states that "Although the companies in each stage develop strategies suited to their own interests, these have an impact on the entire production chain".

ILO (2013) publishes a report covering the process and results of the olive oil value chain analysis in Irbid, Jordan. Different from the traditional value chain analysis which focuses on econometric analysis, they also carry out a decent work in the olive value chain including gender issues. They identify intervention areas for improvement and present a very extensive qualitative analysis as a result of series of trainings and workshops with the stakeholders, but do not provide their quantitative analysis results. Sanz-Canada et al. (2015) focus on the value chain of olive oil from Jaén Mountains, and calculate the profitability of olive oil for different cultivation systems and packaging types along the chain. They demonstrate that many types of olive oil production work with negative profitability, and that "only the 'non-irrigated, medium-yielding' and, mainly, 'intensive irrigated' types obtain positive private profitability values in Jaén, but they only include percentages which vary between 8% and 13% of the cultivation areas of the various olive oil production zones." This finding about the sign of the profitability gives us a clue in profitability formulation in olive oil value chain modeling. Boudi et al. (2016) conduct value chain analysis for the olive oil value chain in Algeria. Using the data and information collected from a sample of actors along the value chain, they construct the olive oil value chain map in Algeria, identify different distribution channels along the chain and calculate the profit margins of stakeholder groups for different type of distribution channels. Additionally, they provide a SWOT analysis and propose a set of value chain upgrading strategies for the sustainability of olive oil value chain in Algeria. Fagioli et al. (2017) propose a methodology to evaluate the value along the agri-food chain depending on its multifunctionality in environmental, social and economic aspects. They use multiple criteria decision making in their evaluation, and also demonstrate their approach for the olive oil value chains in Spain, Italy, Greece, Portugal and France. Freire (2017), from the rural development perspective, analyzes the development of olive oil value chain in Portugal after the second world war. The author presents various political, ecological, technical, commercial and social factors historically, leading to the inclusion of rural olive oil territories in the dynamics of globalization.

4.2 Operations Research (OR) in Agriculture and Food

Operations Research literature in agriculture and food dates back to 50 years or more in attempts to understand and manage them efficiently. In our literature review, we generally focus on more recent studies completed since year 2000.

Olive and olive oil have their own characteristics in terms of their problem environment. When compared to cereals (wheat, corn, etc.), quality of olive fruit is much more sensitive to environmental conditions and especially, perishability of olives after harvesting is a great concern. When compared to fresh produce (such as fruits, flowers and vegetables), olive can be extracted to produce olive oil that can be stored and then marketed. That is, perishability of olive can be avoided when it is converted to olive oil. In our literature review of relevant operations researcher studies, we mainly focus on publications which deal with agricultural products with similar characteristics to olive and olive oil (i.e. grape and wine, citrus and juice etc.). Yet, our literature review is not limited to those publications; other relevant operations research studies on agriculture, food and value chain topics are also reviewed and summarized below.

Literature review studies in OR in agriculture are crucial guidelines in order to understand the research field in general. Weintraub and Romero (2006) extensively review OR literature in both agriculture and forestry at different levels; and they compare two areas in terms of problem types, solution approaches, and reported applications. Ahumada and Villalobos (2009) specifically focus on supply chain management and review the main contributions in production and distribution planning in agriculture. They classify the studies with respect to the optimization approaches used, the type of crops modeled, the scope of the plans and other relevant features. Akkerman et al. (2010) specifically consider food quality, food safety, and sustainability issues and present a comprehensive review on quantitative operations management studies in food distribution. Zhang and Wilhelm (2011) focus on specialty crops, i.e. fruits, vegetables, grapes and wine, etc. They classify OR/MS decision support models with respect to crop type. Soysal et al. (2012) present a review on quantitative models in food logistics systems. They consider three key purposes in three phases of food logistics approaches and make classification of relevant literature accordingly: (1) cost reduction and improved responsiveness in supply chain management, (2) improved food quality and reduction of food waste in food supply chain management, and (3) improved sustainability and traceability in sustainable food supply chain management. Shukla and Jharkharia (2013) focus on fresh produce (fruits, flowers and vegetables) supply chain management literature. They classify the literature with respect to structural attributes such as problem context, methodology, product under consideration, geographic region and also year of publication. Fredriksson and Liljestrand (2015) conduct a literature review on food logistics and classify the studies depending on the logistics activities that they focus on and the perspective of the supply chain actors that they consider. As a very comprehensive guideline in order to capture the diversity of operations research approaches in agriculture, Plà-Aragonés (2015) presents "Handbook of operations research in agriculture and the agri-food industry" which includes nineteen studies with different problems and approaches in the area. Soto-Silva et al. (2016) present the literature review of operations research models applied to the fresh fruit supply chains. Borodin et al. (2016) review the operations research studies which consider uncertainties occurring in the agricultural supply chain management problems. In a more recent literature review study, Utomo et al. (2018) reviews the studies which deal with agri-food supply chain problems with agent based modeling.

One area of interest where operations research and agricultural planning coincide is **harvesting planning and scheduling**. Harvesting operations could be similar to industrial operations in particular aspects; hence, literature on the issue is relatively extensive. The studies in this area enlight us in understanding possible problems that farmers side of the system encounter and available solution approaches. Some relevant studies could be exemplified as follows: Allen and Schuster (2004) focus on the trade-off between cost of investment (fruit processing plant capacity) and cost of fruit harvesting; and determine the optimal rate for a processing plant to receive fruits, grapes. They utilize a news-vendor type model and test their model with representative data from the harvest of a grape-processor firm. Caixeta-Filho (2006) takes the quality of the fruit to be harvested into account; and focuses on the trade-off between maximizing the total soluble solids harvested and maximizing the amount of oranges to be harvested. Higgins and Laredo (2006) take a more strategic viewpoint on the issue in order to improve harvesting and transportation planning of sugar canes. They aim to minimize transportation related costs while determining harvesting and transportation structure. They utilize capacitated p-median modelling and spatial clustering. Ferrer et al. (2008) study on wine grape harvesting and consider both grape quality and operational costs. They use a quality loss function for grapes and utilize a mixed-integer linear programming model to support harvest scheduling, labor allocation, and routing decisions. Bohle et al. (2010) also consider quality, but particularly address uncertainties in wine grape harvesting scheduling optimization. They develop alternative robust models and present results for some test cases obtained from the actual wine industry problems. Ahumada and Villalobos (2011a) focus on the operational side of the fresh agricultural product harvest, and propose a mathematical model for the short term operations of harvesting which maximizes the income of the grower. Herrera-Cáceres et al. (2017) deal with optimization of harvest planning in olive oil production. They present a mathematical model that finds the optimal harvest schedule which maximizes the total amount of olive oil extracted. In the mathematical model, they consider quality standards, operations' requirements, budget and other relevant constraints. They conclude their study with the implementation of the mathematical model to a real life case in Chile.

When our problem context is considered, another relevant area in operations research literature is **agricultural production and inventory planning.** Kazaz (2004) specifically focuses on the olive oil industry. From the standing of an olive oil producer, random yield and demand are considered; and optimal production planning and farm leasing decisions are made using two-stage stochastic programming. In another study, Kazaz and Webster (2011) model the pricing and production planning problem of an agricultural business that leases farm space and experiences supply uncertainty. They again utilize the two-stage stochastic programming approach, where growing of fruit corresponds to the first stage, and after production, selling season of the final product corresponds to the second stage. Noparumpa et al. (2011) focus on production planning decisions of an agricultural firm, specifically a winemaker. Considering the uncertainties in supply and quality of grapes, they formulate a two-stage stochastic programming model that maximizes the expected profit. Shen et al. (2011) study an inventory replenishment model for perishable agricultural products with consideration of collaborative forecasting between a supplier and a retailer.

In operations research literature on agriculture, there is a number of studies on **supply chain management of agricultural products**. Some selected significant studies can be listed as follows: Rong et al. (2011) integrate fresh food quality degradation and production & distribution planning decisions in a fresh food supply chain. They utilize a mixed-integer linear programming model using both food quality and cost criteria. Ahumada and Villalobos (2011b) represent an integrated model for the production and distribution planning of fresh agricultural products. As a significant contribution, they utilize factors that are usually not considered in planning models such as price dynamics and product decay. They represent a mixed integer programming model that maximizes the revenue of the producer. In a following study, Ahumada et al. (2012) consider random variables in order to reflect the variability experienced by producers. They develop a two-stage stochastic programming model for production and distribution plans that consider uncertainty in both market and weather. Paksoy et al. (2012) consider the case of an edible vegetable oil producer in Turkey, and develop a supply chain network design model which simultaneously considers transportation costs between suppliers and silos and transportation costs between manufacturer and warehouses. Yu and Nagurney (2013) present a fresh produce supply chain network oligopoly model with consideration of product perishability and differentiation.

Other interesting **operations research studies on olive oil** are as follows: Siskos et al. (2001) focus on French olive oil market and use multicriteria approach in analyzing consumers' preferences for a new agricultural product. Migdalas et al. (2004) investigate the economic impact of changes in European policy and industry on the olive oil sector, formulate a mathematical model for the olive oil sector in the island of Crete and simulate the olive oil market equilibrium. Amores and Contreras (2009) propose an allocation system for subsidies via internalizing the positive and negative externalities of agricultural activities in olive-growing farms in Andalusia, Spain. In another study from Andalusia, Spain, Alcaide-Lopez-de-Pablo et al. (2014) deal with the analysis of technical efficiency in the olive oil sector in the region.

Operations research studies which specifically focus on **agricultural value chains** can be exemplified as follows: Higgins et al. (2004) focus on the complexity of sugar cane harvesting and transport sectors, and demonstrate the case of Australian sugar cane value chain. With the objective of reduced cost of production, they propose a modeling framework which includes techniques in operations research, financial modeling, and simulation. Taylor (2005) studies red meat as the product, deals with a real red meat value chain in UK and investigates the question if value chain analysis methods that have been developed for the industrial production environments can be appropriately applied in agricultural value chains. As a fundamental study on agricultural value chains, Higgins et al. (2010) explain that complex systems science methods are required for practicing OR in agriculture value chain problems. They demonstrate how three complex system methods, which are agent-based modeling, system dynamics modeling and network analysis, can be applied to agricultural value chains in order to understand the system dynamics under different dynamic conditions.

As it is mentioned in Chapter 3, our modeling purpose is to understand the complex dynamics along the agricultural value chains and provide a quantitative analysis for olive oil value chain in Turkey. Hence, we utilize system dynamics modeling which is one of the complex system science methods that Higgins et al. (2010) recommend. In line with our purpose, we first present an overview of system dynamics modeling approach and then review the related system dynamics modeling studies in the following sections.

4.3 Overview of System Dynamics Modeling Approach

The problem as we define in Chapter 3 is a dynamic policy analysis problem. The term "dynamic" indicates that "it changes over time". In the olive oil industry, as in many industries, stakeholders take actions, observe the outcomes, appreciate the results, then take new actions accordingly, observe the new outcomes, appreciate the new results which then lead to new actions. This structure constitutes "feedback loops". One common example of feedback loops is the price oscillations: as olive oil price decreases, demand increases, hence consumption increases; olive oil inventory levels decrease, then olive oil price increases and so on. This structure also brings about nonlinear relationships: the effect (output) observed is not directly proportional to the cause (input). Hence, policy and scenario analysis in Turkish olive oil value chain, as in almost every value chain, turns out to be a nonlinear dynamic feedback problem.

Nonlinear dynamic feedback problems are typically impossible to be represented mathematically and solved by "prescriptive" models, such as optimization models (Barlas, 2002). In such cases, we usually resort to "descriptive" models which do not directly provide a policy recommendation, but the modeler, using the model, derives the policy recommendations via a set of simulation experiments.

Most agricultural commodities experience cycles in prices and production with characteristic periods, amplitudes and phases. In these agricultural commodity markets, the negative feedback loops through which price seeks to equilibrate supply and demand often involve long time delays, leading to oscillation. Yet, the classical economic theory of commodity cycles (also known as cobweb models) are not able to capture the market dynamics (Sterman, 2000). Deaton and Laroque (1992 and 1995) develop non-dynamic models and study on explaining commodity prices with respect to competitive storage and auto-correlation functions; then again Deaton and Laroque (1996) attempt to define the price of an agricultural commodity as correlated with the harvest amount. Yet, they state that "storage seems to play only a small part in generating the auto correlation in prices" and "the results are disappointing since much of the complexity in the econometrics comes from handling the speculative storage".

Sterman (2000) lists the reasons why cobweb models are not able to capture market dynamics as such:

- They do not represent the stock and flow structure of real markets, including inventories, work in process and production capacity.
- They are formulated in discrete time.
- The interval between periods is assumed to correspond to the time required to produce the commodity, such as the gestation and maturation time for livestock. However, the observed period of commodity cycles are much longer than the production delays.
- They do not distinguish between production capacity and capacity utilization, so cannot explain the multiple oscillatory periods.

In this study, focusing on the value chain of an agricultural product, we aim to build a nonlinear, dynamic, descriptive and time continuous system dynamics model in order to make quantitative policy and scenario analyses for the Turkish olive oil value chain. In the following section, we present a literature review on system dynamics modeling studies on somehow relevant topics.

4.4 System Dynamics Modeling Literature Review

Agricultural value chain analysis and development is an interdisciplinary research area and comprehension of the dynamics in agricultural value chains requires a thorough literature review. Above all, understanding agricultural value chains is strongly related to the analysis of commodity market behavior. As a milestone in understanding commodity market behavior with system dynamics modeling, Meadows (1969) proposes "Dynamic Cobweb Theorem" and explains cyclic behaviors in commodity markets. Later, in his comprehensive book on system dynamics, Sterman (2000) presents an updated version of Generic Commodity Market model based on Meadows (1970). The studies that focus on commodity markets since then generally follow the commodity modeling principles proposed by Meadows (1969, 1970) and Sterman (2000) as a baseline.

In the following section, we first present the summary of some selected system dynamics studies on commodity and industrial market dynamics. Then, we present an overview of the related system dynamics studies on food and agriculture. As the most crucial part of our literature review, then we present the review of system dynamics studies which specifically focus on agricultural commodity market dynamics and consider agricultural supply chain and value chain structures. In the final part of the section, we conclude with our contribution to the existing literature.

4.4.1 System Dynamics Modeling in Commodity and Industrial Markets

In understanding value chain dynamics, we start with system dynamics modeling studies in commodity and industrial markets. Before focusing on agricultural commodity markets, we present a summary of the studies that deal with non-agricultural markets.

One stream of studies investigates **the resource use dynamics and the related markets.** In the literature, there are several examples of systems dynamics studies on water resource management, land use management, energy policy making and other natural resource planning problems. Van Vuuren et al. (1999) focus on the issue of sustainability of the global metal resource use. They build a system dynamics model which simulates long-term trends in production and consumption of metals considering impacts such as ore-grade decline, capital and energy requirements and waste flows. Bantz and Deaton (2006) describe the formulation of a system dynamics model of the U.S. biodiesel market. They discuss the possible growth behavior scenarios for the industry over the next decade. Chi et al. (2009) present a system dynamics model representing natural gas industry in the UK. After they build up and validate their model, they make policy analysis on different taxation policies, different demand levels and possible advances in technology. Winz et al. (2009) present a comprehensive study on the use of system dynamics in order to address dynamically complex problems in water resources management. They present a comprehensive literature review on system dynamics in water management and discuss a number of best practices in the area. They argue that system dynamics combined with stakeholder involvement provides an appropriate methodology to address issues such as regional planning and river basin management, urban water management, flooding and irrigation. Glöser and Hartwig (2015) study the dynamics of raw material markets and commodity price fluctuations caused by delayed adjustment of supply and develop a simple system dynamics model aiming at reproducing real market behavior of industrial metals. In a following study, Glöser-Chahoud et al. (2016) investigate the price movements in global industrial metal markets and take the global copper market as an example. They relate the commodity price fluctuations to the delayed adjustment of supply and demonstrate the appropriateness of the dynamic cobweb model to global industrial metal markets.

Another stream of studies focus on **dynamics of industrial markets**. Lyneis (2000) proposes the idea that calibrated system dynamics models are likely to be better and more informative than other forecasting approaches. He illustrates the idea with examples from a model of the commercial jet aircraft industry. Berends and Romme (2001) investigate the cyclic behavior in capital-intensive industries and apply their model to the U.S. paper industry. Jones et al. (2002) deal with the interrelated questions on stability, sustainability and equity in lumber industry. In modeling and policy analysis stages, their primary focus is on sustainability. Chen and Jan (2005) investigate the semiconductor industry in Taiwan. They analyze the development of the industry which requires long-term accumulations of capital, technology, human resources, and production capacity. After they test their model with the historical settings, they make analysis with two scenarios. In one scenario, availability of human resources decreases while in the other one, the semiconductor job market loses its attractiveness. Kumar and Yamaoka (2007) study the Japanese automotive industry's closed loop supply chain. Their aim is to investigate the relationships between reduce, reuse and disposal in the Japanese car market with system dynamics modeling. They make a base model analysis and conclude their study with scenario analysis on dramatic changes in used car export rate. Ghaffarzadegan and Tajrishi (2010) focus on the price behavior and price instability in cement market during and after the economic transition in Iran. Pierson and Sterman (2013) study the cyclical behavior in airline industry earnings and analyze the strategies to mitigate the cycle. Even though System Dynamics tools are mainly applied to provide insight into long-term developments, Kapmeier and Voigt (2013) challenge this assumption and present a short-term price forecasting model developed for a large global petrochemical company.

4.4.2 System Dynamics Modeling in Agriculture and Food

System dynamics modeling is widely used in agriculture and food system problems. In this section, we summarize an overview of some selected studies which deal with the variety aspects of agriculture and food systems.

One stream of studies that we review focuses on **food and agricultural supply chain and production**. Minegishi and Thiel (2000) study poultry production in France, describe the possible outcomes of an infection to the supply chain of the chicken industry and make certain recommendations to managers. Georgiadis et al. (2005) study the strategic supply chain management with system dynamics methodology with an application to multi-echelon network of a major Greek fast food chain. Sachan et al. (2005) present a systems dynamics model in order to determine total supply chain cost of an Indian grain chain. They evaluate different scenarios which are the cooperative model, contract farming and a collaborative supply chain based on optimistic, pessimistic and most likely views. Kumar and Nigmatullin (2011) investigate supply chain performance for a non-perishable food product. With a system dynamics model representing the supply chain, they examine the effect of demand variability and lead-time on supply chain performance. Teimoury et al. (2013) investigate the supply chain of perishable fruits and vegetables with the influence of import quota policies. Their goal is to determine the best import quota policy by considering the trade-offs among price mean, price variation and markup.

Another relevant stream of studies focuses on **food security**. Giraldo et al. (2008) focus on availability of food, the stability of food security and explore the food security process from a national approach for developing countries. The study is concluded with a causal loop diagram and representation of stock and flow structure without presenting any analytical or mathematical relationships. Kim (2009) examines the world food and energy resources, analyzes the trends of crude oil and biofuel prices, and formulates the food-energy links mechanism. Then, via a system dynamics model, she both analyzes the global cereals market and energy market, and makes forecasts for the global production, consumption, and stock of those markets by 2030. Without explicitly presenting the analytical and mathematical relationships between model elements, she presents the results of concluding simulation runs. Ayenew and Kopainsky (2014) focus on problems causing food insecurity in Ethiopia. In order to investigate the policy alternatives to reduce the problem; they build, calibrate and test a system dynamics model that integrates population, food production, and market dynamics. Khodeir and Abdel-salam (2015) build a System Dynamics Model that represents imports, demand and consumption of wheat in Egypt. They consider the increase in population undernourishment and filling the gap between the desired quantity and the supply of wheat. Gerber (2015) analyzes the dynamics between food security, agriculture and natural resources using Zambia as the study case. He integrates agronomic and agricultural economic theory to develop a System Dynamics Model. He makes policy analysis with different levels of subsidies. Herrera and Kopainsky (2015) propose a framework to assess resilience into system dynamics models. With this framework, they compare different policies to improve the maize production of Jutiapa, Guatemala, and analyze the structural causes of their differences.

Another relevant stream of studies is on the **development of food and agricultural sectors** some of which can be exemplified as follows: Ozolins et al. (2007) evaluate some possible development scenarios of the agricultural sector in Latvia with system dynamics approach. They investigate growth and balancing forces of the agricultural economics along with dynamics of capital, land and labor allocation. In a very comprehensive but rather a macro level study, Johnson et al. (2008) present the dynamic Policy Model of Multifunctional Agriculture and Rural Development (POMMARD), that is built collaboratively by a research team of policy analysts from 11 European countries. Their goal is to build an interdisciplinary model of agriculture and rural development for policy analysis that includes Land, Agriculture, Tourism, Region, Human Resources, Non-commodities, Capital, and Quality of Life sections. Haghighi (2009) aims to determine the optimal employment and production policies in the Iranian agricultural sector. He uses System Dynamics framework combined with econometric methods based on the economics theory. Acuña and Riojas (2011) use system dynamics approach to explain how agricultural systems work and analyze the dynamic effects of the principal policies in support of traditional agriculture on the profit of peasants as enterprise farmers. Rozman et al. (2012) study the system dynamics of organic farming development and focus on strategic questions related to the level of organically utilized area, levels of production and crop selection in a long term dynamic context. They make scenario analysis with 7 different scenarios and analyze the impact on economic and environmental parameters of organic production. Mohammadhashem (2014) analyzes agricultural employment and production in Fars Province while taking production, investment, rural wages, rural population, unemployment level and emigration into consideration.

4.4.3 System Dynamics Modeling in Agricultural Commodity Markets

Stating once more, the aim of our study is to understand the dynamics in agricultural value chains and to make policy and scenario analysis with a valid system dynamics model built for the olive oil value chain in Turkey. Hence, in this final section of the literature review, we narrow down our point of interest and we provide a summary of the selected literature specifically in the areas of agricultural commodity markets, agricultural value chains and policy analysis. We mainly focus on the system dynamics modeling studies that consider:

- at least one of these chain structures for agricultural commodities: the supply chain (i.e, flow and physical transformation of the product from seed to fork) and the value chain (i.e. formation of added cost and price elements during flow and transformation),
- the interplay among four major market components: price, demand, supply (short term), and capacity (long term supply),

One group of studies focuses on **price and supply volatility in agricultural commodity markets**. Nicholson and Fiddaman (2003) focus on dairy products and discuss the sources of price volatility and also relationship between dairy policy instruments and price variations. In a more conceptual modeling study, Conrad (2004) deals with the effects of large-scale disruptive events for agricultural commodity markets, namely corn, beef, and dairy sectors. Arquitt et al. (2005) build a system dynamics model to study the underlying causes of boom and bust in the shrimp aquaculture industry and also to propose policies with the concern of sustainability. Osorio and Arango (2009) build a simple system dynamics model for the world coffee market. In their model, they consider price dynamics, investments, production capacity, inventory and demand. They complete their study without calibrating their model with respect to real world data, hence they conclude their study with the results of initial tentative runs. In order to investigate food security and understand food system vulnerability at the country level, Gerber (2014) and Stave and Kopainsky (2014) present comprehensive conceptual modeling studies. Gerber (2014) studies the national level food security as the outcome of food systems. In the form of causal diagrams, he presents a generic framework of a food system with food security indicators at the country level. Stave and Kopainsky (2014) present the causal structure of their model to the problem of food system vulnerability and resilience in developed countries.

Another group of studies investigates **the impacts of new policies on the agricultural commodity markets and agricultural value chains**. Pagel et al. (2002) deal with dairy products and focus on farm behaviour. They study the effects of governmental interventions on the distribution of farm sizes and on the number of farms in dairy industry. Declerck and Cloutier (2006) focus on the vertical coordination efforts in a cobweb economy to manage risk and uncertainty, and select the champagne industry for the application. Arquitt and Cornwell (2007) examine the effects of ecolabeling in farmed shrimp industry by means of a system dynamics model. Guimaraes et al. (2009) develop a system dynamics model to understand herd dynamics of dairy goats and analyse management policies in Brazil. They investigate the effects of reproduction index, mortality rate and breeding seasons with a 10-year-long simulation and sensitivity analysis. For a similar problem area, Turner et al. (2013) build a system dynamics model to investigate the dynamics of a cow-calf ranch under various marketing scenarios. They perform scenario analysis on return on investment and net income for different sales scenarios. Rich and Dizyee (2016) focus on the potato value chain improvements against climate change in Bihar. They provide insightful quantitative analysis for farm income and consumer surplus under different scenarios.

Another group of studies does not only **focus on policy analysis in agricultural commodity markets** but **also consider different price levels along the agricultural value chains.** An important agricultural commodity for Mexico, coffee market, is examined by Andersen et al. (2008). They investigate the effects of Full Information Pricing Networks, especially non-price information such as being "organic" or "fair trade" in coffee pricing. They distinguish the producer price from the retailer price and use a sophisticated pricing structure for both price levels rather than using a given profit margin. Yet, since they do not provide any information for model validation results or any comparison for the simulated vs. historical data, the validity of their approach can not be fully understood.

Nicholson and Stephenson (2014) investigate the effects of a margin insurance program under which dairy farmers can receive indemnity payments from the U.S. government if a margin falls below the insured level. In this study, they use two different price levels and differentiate "farm milk price" from "dairy product prices". They study whether the corresponding governmental intervention weakens feedback processes that would adjust milk production, prices and margins. They make scenario analysis and stochastic simulations for different market conditions. Simoes et al. (2017) also study the dairy product market but they focus on the impact of production technology on farm milk prices. They develop a model to test the hypothesis that the improvement of technology in herd management can reduce the oscillations in the price paid to dairy farmers. Similar to Nicholson and Stephenson (2014), Simoes et al. (2017) consider the difference between retailer price and consumer price. The common point of these studies in pricing structure is that the price in one level (i.e. dairy product price in Nicholson and Stephenson (2014) and producer price in Simoes et al. (2017)) is a function of a margin coefficient and the price in the other level (i.e. farm milk price in Nicholson and Stephenson (2014) and retail price in Simoes et al. (2017)).

Hamza et al. (2014) investigate the effect of interventions that provide veterinary services and improve information flows along a smallholder value chain for goats. Additionally, as an important contribution to the existing literature, Hamza and Rich

(2015) provide a handbook for applying system dynamics techniques in value chains and illustrate their techniques with an application to pig value chains. In another study for livestock market, Parsons and Nicholson (2017) investigate the impacts of potential regional policy options for Mexico's sheep sector. In a like manner to the previous examples, sheep price is considered as a direct function of meat price. On dairy value chains, Liu and Arthanari (2016) and Lie and Rich (2016) provide two very insightful but conceptual modeling studies.

Bala et al. (2017) model the rice supply chain in Bangladesh from farmers to consumers considering rice demand and production capacity as exogenous components. The strong assumption of the paper is that the order quantity is assumed to be determined by EOQ (economic order quantity), which is somehow questionable in the case of their problem setting. They analyze different supply chain management scenarios via sensitivity analysis type experiments. In another study for the same commodity, Chung (2017) specifically investigates the effects of the removal of price controls and also an import monopoly on the rice prices and self-sufficiency levels in Malaysia. The author assumes that the rice demand is exogenous to the model boundary. One important aspect of the study is that they distinguish market prices in three levels: paddy price, wholesale price and retail price, where paddy price and retail price are direct functions of endogenously generated wholesale price.

In a recent remarkable work, Dizyee et al. (2017) provide a sophisticated modeling and application study on beef value chains in Botswana. They build a system dynamics model which considers the biological dynamics of cattle production, the economics of animal and meat marketing and trade, and the impacts that environmental pressures such as rainfall and animal disease have on the system. They investigate the profits of different value chain actors under different scenarios. In a more recent study, Lie et al. (2018) investigate the policy options for dairy value chain development in Nicaragua with a comprehensive dairy value chain model.

4.5 Contribution of Our Study to the Existing Literature

The contribution of our study to the existing literature can be assessed in various aspects.

We remind you of our dynamic hypothesis: the relationships among the price levels along the agricultural value chain are not linear; one price level can not be explained as a linear function of another. Additionally, our modeling purpose is to understand the price, supply and demand dynamics along the agricultural value chains as a whole. In the previous section, we summarize the existing system dynamics literature dealing with agricultural value chain problems. As for the main contribution of our study to the existing **system dynamics literature**, we build a unique system dynamics model for agricultural value chains incorporating the three characteristics below simultaneously:

- including both supply chain (i.e., flow and physical transformation of the product from seed to fork) and value chain (i.e., formation of added cost and price elements during flow and transformation) structures,
- considering the four major market elements; price, demand, supply, and capacity, endogenously,
- considering complex nonlinear relationships among the price levels in different stages of the agricultural value chain, instead of assuming simple linear relationships, like, for example, the retail price as a linear function of fruit price and a given retail mark-up.

From the viewpoint of **value chain analysis**, as mentioned before, Rich et al. (2009) state that the limitation of current value chain analysis studies is their "inability to analyze specific, chain-level policy interventions and assess their impacts." When the existing literature on **olive oil value chain** is considered, our study is unique in terms of quantitatively assessing the results of possible value chain development policies.

Within the scope of **operations research**, we remind that Higgins et al. (2010) explain that complex systems science methods are required for practicing operations research in agriculture value chain problems. Yet, the number of operations research studies in agricultural value chain applications is quite much limited. As the contribution of our study to the existing operations research literature, we demonstrate the use of complex systems science methods and mathematical modeling techniques in order to understand and analyze the agricultural value chains.

CHAPTER 5

THE AGRICULTURAL COMMODITY VALUE CHAIN MODEL

In this chapter, the structure and the behavior of the generic Agricultural Commodity Value Chain Model is presented with its modules, assumptions, variables and equations. The agricultural commodities in focus have the following characteristics: they are found and traded in different forms of food along the value chain, the raw fruits or plants are harvested at specific times of the year and they are perishable when harvested, then they go through some processes and become bulk food which is storable. The commodity couples which have similar characteristics can be exemplified as fresh vegetables - vegetable oils, citrus - juice and fresh nuts - dried nuts. For the initial modeling efforts for the specific case of olive oil, see Atamer Balkan and Meral (2017).

The Agricultural Commodity Value Chain Model consists of nine interacting modules. The relationships among these nine modules are depicted in Figure 5.1.

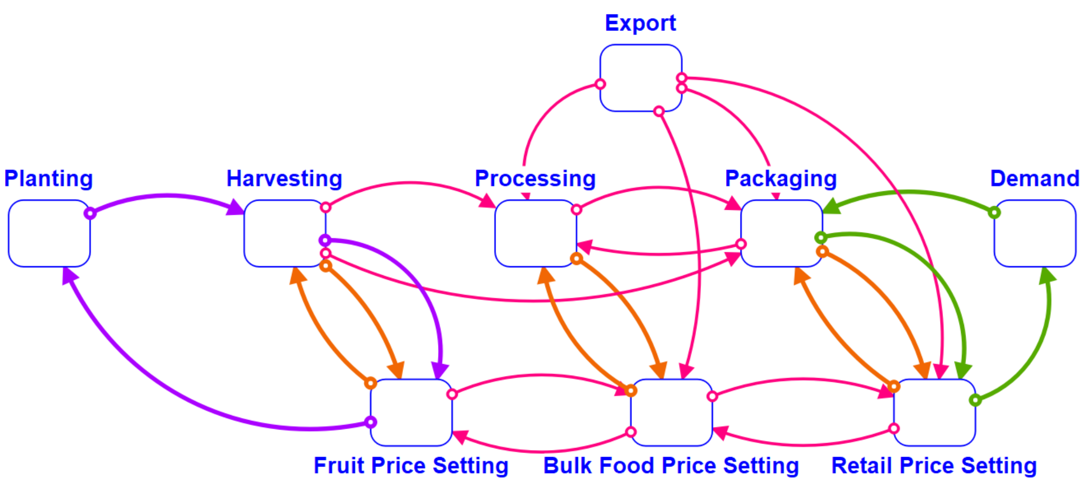

Figure 5.1: Modules of Agricultural Commodity Value Chain Model

The modules in the upper part, from Planting to Demand represent supply chain operations and the physical transformation of the product from tree to consumers' table. On the lower part, Fruit (Raw Food), Bulk Food and Retail Price setting modules represent the value chain formation and the evolution of costs and prices from the raw material to the finished product.

5.1 Definitions

In this section, definitions and the boundaries of the supply chain operations are given before getting into modeling details.

5.1.1 Different Forms of Food along the Value Chain

Fruit, Bulk Food and Packaged Food: The corresponding agricultural commodity can be found and traded in three forms along the value chain: **Fruit** (i.e. perishable raw food), **Bulk Food** (i.e. processed and storable work-in-process food), **Packaged Food** (i.e. finished food product for retail). Fruit is the output of the Harvesting stage, Bulk Food is the output of the Processing stage and Packaged Food is the output of the Packaging stage.

For the sake of simplicity and consistency, commodity in the form of perishable raw food/plant/fruit is generally referred as **Fruit** throughout the rest of the text.

5.1.2 Planting

Planting: In our problem definition, planting process only consists of planting seeds or saplings to the soil and does not include the plant care operations afterwards. Depending on the geographical conditions and the characteristics of the plant, planting can only be performed in predetermined times or seasons of the year.

Planting Costs: Planting costs consists of unit cost of sapling or seeds and machine and labor of planting. Planting costs do not include the cost of farming area. It is assumed that planting is done on a farmland which is already owned by the farmer.

For the sake of simplicity and consistency, the mature form of saplings and seeds (i.e. the agricultural source of the fruit in soil) is generally referred as **Tree** throughout the rest of the text.

5.1.3 Harvesting

Harvesting: Within the context of our problem setting, harvesting consists of operations which are handled after planting saplings or seeds until obtaining and collecting the fruit. It includes all activities regarding tree growing and fruit harvesting: soil management, irrigation, pruning, fertilization, fruit collection and all corresponding logistics activities.

Fixed Costs of Harvesting: Fixed Costs of Harvesting include the costs regarding growing and farming activities. It represents all infrastructure, machine and labor costs regarding soil management, irrigation, pruning, fertilization etc. Since these activities are conducted as farming area-based or tree-based, not product-based, these costs are assumed to be fixed costs.

Variable Costs of Harvesting: Variable Costs of Harvesting consist of unit machine and labor costs regarding fruit collection and transportation. Since these costs alter with the magnitude of the fruit harvest, they are assumed to be variable costs.

5.1.4 Processing

Processing: Processing operations, in general, consist of fruit reception to the processing unit, fruit processing and storage activities. Depending on the characteristics of the fruit, processing activities can include extraction, heating, drying, mixing, cooling etc. Within our problem context, the key thing about processing activities is, they are conducted to transform the raw fruit into a storable bulk food (i.e. olive fruit to olive oil, citrus to fruit juice, fresh fruits to dried fruits etc.).

Fixed Costs of Processing: Fixed Costs of Processing consist of regarding infrastructure, marketing and overhead costs.

Variable Costs of Processing: Variable Costs of Processing includes unit machine and labor costs of fruit or plant reception, processing and bulk food storage costs.

5.1.5 Packaging

Packaging: Packaging activities include bulk food collection logistics, fine-tuning manufacturing operations before packing (cleaning, filtering, blending etc.), packing operations and storage of the packaged product. Within our problem context, distribution, warehousing and selling operations are also included in boundaries of Packaging process.

Fixed Costs of Packaging: Fixed Costs of Packaging mainly consists of infrastructure, business and financial costs regarding packaging operations.

Variable Costs of Packaging: Variable Costs of Packaging consists of unit bulk food collection logistics, manufacturing, packing and packaging, labeling, packaged food storage and distribution logistics costs.

5.1.6 Price Setting

Fruit Price: The output of Harvesting stage is Fruits harvested. Fruit Price is the unit price of the fruits which are ready to be used in Processing stage. Hence, Fruit Price also serves as the raw material cost of the Processing stage.

Bulk Food Price: Similarly, the output of Processing stage is Bulk Food. Bulk Food Price is the unit price of the bulk food which are ready to be stored as bulk or to be used in Packaging stage, depending on the decision of relevant stakeholders. Hence, Bulk Food Price also serves as the raw material cost of the Packaging stage.

Retail Price: The output of Packaging stage is Packaged Food. Retail Price is the unit price of the packaged food which are ready for consumption.

Profitability: Profitability of an operation is calculated in order to capture the short term earning of performing the regarding operation, i.e., the unit profit of additional one unit obtained as the output of the regarding operation. It is mainly calculated as the expected price of the output minus the expected variable cost of the operation. If there is a financial aid which supports the unit benefit of the operation, then it is also included in the profitability calculations. In the model, profitabilities of the operations are calculated in variables **Expected Profitability of Harvesting**, **Expected Profitability of Processing** and **Expected Profitability of Packaging**.

5.2 Assumptions

- The agricultural output under consideration is a commodity and the corresponding market is competitive.
- The commodity supply chain has a “push” structure instead of a “pull” structure.
- The commodity is produced and consumed in the domestic market, exported to the world market, but not imported or import values are so small that they can be ignored.
- The agricultural value chain in the model is in a developing country setting where the country is a price taker, not a price maker in the world market.
- The monetary values in the model such as prices, costs, financial supports etc. are real values.
- Quality differentiation among commodities is ignored.
- Unit fixed costs of operations are independent of harvesting, processing and packaging volume.
- Consumer price of the substitute commodity is independent of the consumer price of the agricultural commodity in the model.

- Packaging Rate and Consumption Rate are much higher than a theoretical deterioration rate of bulk food and packaged food, hence deterioration rate flows are not required to be defined in bulk and packaged food inventories.
- The exogenous variables below are assumed to be positive; they do not drop down to absolute 0 value:
  - Planting Costs
  - Bulk Food Export Price
  - Packaged Food Export Price
  - Expected Fixed Cost of Harvesting
  - Expected Variable Cost of Harvesting
  - Expected Fixed Cost of Processing
  - Expected Variable Cost of Processing
  - Expected Fixed Cost of Packaging
  - Expected Variable Cost of Packaging
  - Population
  - Substitute Price
  - Market Trend
  - GDP

5.3 Summary of the Model Structure and Behavior

The main structures and the behavior of the model can be summarized as follows: As a result of fruit supply quantity, the market price of the fruit emerges and it affects the perception towards the profitability of farming business. Depending on the profitability perception, farmers either plant new trees (similar to capacity expansion decision of a manufacturer) or do not.

Tree stock level affects the number of bearing trees and hence the fruit supply. After the fruit harvest, a known portion of fruits (depending on the characteristics of the fruit) is processed in order to obtain bulk food. Bulk food is either exported or sent to domestic production facilities for additional processes such as filtering, packaging and labeling. Bulk food price is determined by several exogenous and endogenous effects which include bulk food supply and fruit price.

Packaged food supply depends on the profitability of packaging operations. Similar to bulk food, packaged food is either exported or sent to domestic retailing points and becomes available for consumption in the domestic market. Retail price represents the consumer price in the domestic market. Demand and consumption levels are determined by the retail price and other social or economical factors for the end consumers in the domestic market.

Model boundary chart with both endogenous and exogenous components and the excluded elements can be seen in Table 5.1.

Table 5.1: Model Boundary Chart

Endogenous	Exogenous	Excluded
Tree Stock	Financial Supports	Quality Differentiations
Tree Planting Operations	Planting Costs	Environmental Effects
Harvesting Operations	Harvesting Costs	
Processing Operations	Processing Costs	
Packaging Operations	Packaging Costs	
Consumption	Distribution Costs	
Bulk Food Inventory	Selling Costs	
Packaged Food Inventory	Harvest Period	
Fruit Price	Share of Bearing Trees	
Bulk Food Price	Share of Fruits for Process.	
Retail Price	Processing Yield	
	Export Price	
	Export Quantities	
	Population	
	Substitute Price	
	GDP	
	Market Trend	

At first glance in Figure 5.1, several loops can be observed among the modules. The major balancing feedback loops in the model can be summarized as follows:

The major balancing loop in the model can be generally stated as the "Price $\rightarrow$ (Supply) Rate $\rightarrow$ Inventory $\rightarrow$ Inventory Coverage $\rightarrow$ Price" loop. For tree stock level, fruit price affects the plantation rate. The stock of trees behaves as the capacity level of the whole system. This loop (shown with violet arrows in Figure 5.1) corresponds to the capacity acquisition loop and it represents the behavior of **the long term supply curve**. For bulk food or packaged food inventories, the fruit price affects the harvest rate and the retail price affects the packaging rate. That is, the harvest utilization and the production capacity utilization levels depend on the price and hence expected profitability of current operations. These loops (shown with orange arrows in Figure 5.1) correspond to the capacity utilization loop and represents the behavior of **the short term supply curve**.

Another major balancing loop in the model is on the **demand** side: "Demand $\rightarrow$ Consumption Rate $\rightarrow$ Inventory Coverage $\rightarrow$ Retail Price $\rightarrow$ Demand" loop (shown with green arrows in Figure 5.1). Demand function consists of retail price, substitute price, market trend, purchasing power, population and other social or technical factors. This structure corresponds to the behavior of the **demand curve**.

The model is built with the system dynamics modeling software, Stella Architect (version 1.7.1) and it consists of 178 variables 10 of which are stocks, 16 of which are flows and 152 of which are converters. In the following sections, the main structures, behavior and the equations of the modules are provided.

5.4 Planting Module

In an agricultural value chain setting, tree stock behaves as the raw material production capacity of the industry. Hence, Planting Rate is defined as similar to a long term supply function. Model structure of Planting module is theoretically based on Production Capacity and Desired Capacity sectors given in General Commodity Model by Sterman (2000). These two sector structures are adapted to the agricultural setting and reformulated accordingly. Stock and flow structure for Planting can be seen in

Figure 5.2. The detailed explanations on the model formulation is given below.

$$\textbf{Mature Trees (t)} = \text{Mature Trees (t - dt) +}$$
$$\text{(Maturation Rate - Death or Removal Rate) * dt.} \quad (5.1)$$

Number of Mature Trees increases with the Maturation Rate and decreases with their Death or Removal Rate.

$$\textbf{Death or Removal Rate} = \text{Mature Trees / Life Time.} \quad (5.2)$$

It is assumed that there is an average Life Time of the tree of the corresponding agricultural commodity, and Death or Removal Rate is determined by the available Mature Tree stock divided by average Life Time.

$$\textbf{Maturation Rate} = \text{DELAY3 (Planting Rate, Maturation Time).} \quad (5.3)$$

Similar to the Acquisition Rate formulated in Generic Commodity Model by Sterman (2000), Maturation Rate is formulated as the third order exponential delay function of Planting Rate and Maturation Time. For structure of higher order material delays, see Appendix A.

$$\textbf{Life Time} = \text{Constant.} \quad (5.4)$$

$$\textbf{Maturation Time} = \text{Constant.} \quad (5.5)$$

Life Time and Maturation Time are time constants which represent the average life time and average growth time of a tree, respectively.

$$\textbf{Young Trees (t)} = \text{Young Trees (t - dt) + (Planting Rate - Maturation Rate) * dt.} \quad (5.6)$$

Number of Young Trees increases with the Planting Rate and decreases with the Maturation Rate.

$$\textbf{Planting Rate} = \text{MAX (0, Indicated Planting Rate) * Planting Period.} \quad (5.7)$$

Planting Rate is formulated with the standard stock management structure. It is equal to Indicated Planting Rate as soon as Indicated Planting is non-negative. If Indicated Planting Rate is found to be negative, then Planting Rate is equal to 0.

$$\textbf{Planting Period} = \text{IF ((TIME MOD 12)} \geq \text{PT1 AND (TIME MOD 12)} < \text{PT2)}$$
$$\text{THEN 1 ELSE 0.} \quad (5.8)$$

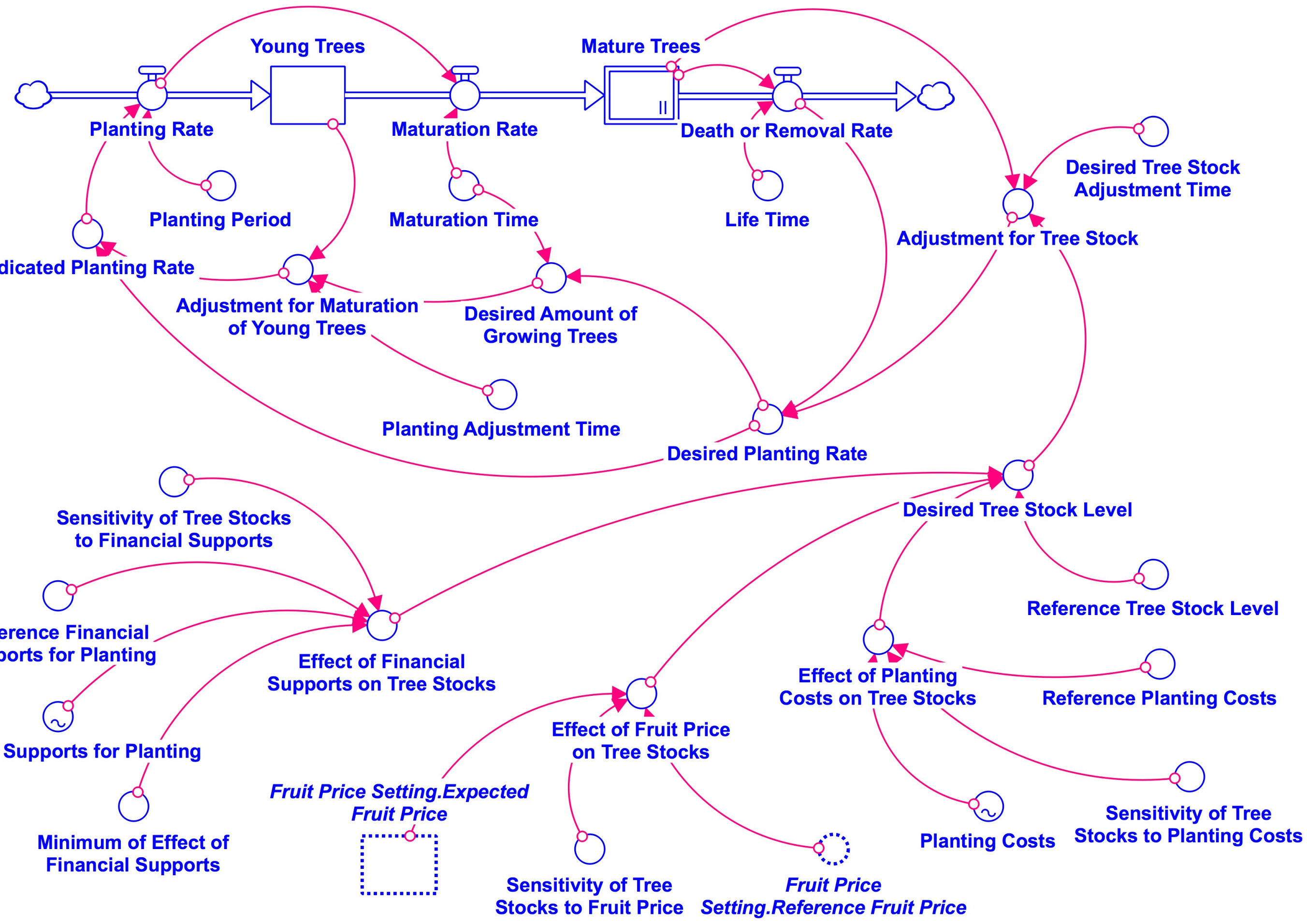

Figure 5.2: Stock and Flow Diagram of the Planting Module

Planting period variable is a logical expression which checks that whether TIME in model is within the planting period or not. Time unit of our model is months and the expression above indicates that, planting period is between months PT1 and PT2 within a year.

Indicated Planting Rate $=$ Adjustment for Maturation of Young Trees
+ Desired Planting Rate. (5.9)

Indicated Planting Rate is the Desired Planting Rate adjusted by the adequacy of the Maturation of Young Trees.

Adjustment for Maturation of Young Trees = (Desired Amount of Growing Trees - Young Trees) / Planting Adjustment Time. (5.10)

Adjustment for Maturation of Young Trees aids to correct the gap between the desired and actual number of growing trees.

Desired Amount of Growing Trees = Maturation Time * Desired Planting Rate. (5.11)

The desired amount of growing trees is the amount of young trees which are to be growing to yield the desired planting rate.

Desired Planting Rate $=$ Death or Removal Rate + Adjustment for Tree Stock. (5.12)

Adjustment for Tree Stock $=$ (Desired Tree Stock Level - Mature Trees) / Desired Tree Stock Adjustment Time. (5.13)

The desired planting rate consists of the replacement of expected deaths and removals, adjusted in response to the gap between desired and actual tree stocks.

Desired Tree Stock Adjustment Time $=$ Constant. (5.14)

Planting Adjustment Time $=$ Constant. (5.15)

Desired Tree Stock Adjustment Time and Planting Adjustment Time are the average time periods required to adjust the desired tree stock level and the plantation of young trees, respectively.

Desired Tree Stock Level = Reference Tree Stock Level * Effect of Financial Supports on Tree Stocks * Effect of Fruit Price on Tree Stocks * Effect of Planting Costs on Tree Stocks. (5.16)

Desired Tree Stock Level is assumed to be increasing with financial supports and fruit price, and decreasing with planting costs. Sterman (2000) modeled Desired Capacity with only one effect function, "Effect of Expected Profit on Desired Capacity" and calculated "(Expected Long-Run Price - Expected Production Costs) / Expected Long-Run Price" to find the expected profitability. Yet, in our setting, planting costs and financial supports occur once in the lifetime of a tree, whereas fruit price occurs for whole yield of a tree for every harvest period. Additionally, in some harvest seasons, financial supports may exceed planting costs which changes the sign of "Planting Costs - Financial Supports". Since financial supports, fruit price and planting costs are not comparable in terms of magnitude and occurrence frequencies, they are not concatenated in one single "profit" function in our model. Alternatively, they are formulated as three separate exponential effect functions.

Effect of Financial Supports on Tree Stocks = MAX (Minimum of Effect of Financial Supports, (Financial Supports for Planting / Reference Financial Supports for Planting) ^ Sensitivity of Tree Stocks to Financial Supports). (5.17)

Effect of Fruit Price on Tree Stocks = (Expected Fruit Price / Reference Fruit Price) ^ Sensitivity of Tree Stocks to Fruit Price. (5.18)

Effect of Planting Costs on Tree Stocks = (Planting Costs / Reference Planting Costs) ^ Sensitivity of Tree Stocks to Planting Costs. (5.19)

Effect of Financial Supports on Tree Stocks, Effect of Fruit Price on Tree Stocks and Effect of Planting Costs on Tree Stocks are formulated as exponential effect functions as explained in Appendix A. Depending on the relative value of the corresponding variable to its reference value, effect variables take on values higher than or smaller than 1. Effect of Financial Supports is bounded with a minimum value, since its behavior in extreme values is different than the other two effects. Consider the Effect of Fruit Price on Tree Stocks: for very small values of Expected Fruit Price, it is expected that Effect of Fruit Price on Tree Stocks take very small values which indicates that "decision makers give up planting trees". Yet, when we consider Effect of Financial Supports on Tree Stocks, we know that even though there is no financial support, decision makers do not completely give up planting trees. Hence, a Minimum of Effect of Financial Supports is defined.

$$\textbf{Minimum of Effect of Financial Support} = \text{Constant.} \tag{5.20}$$

Minimum of Effect of Financial Supports is defined as a constant which is strictly smaller than 1.

$$\textbf{Financial Supports for Planting} = \text{Graphical function.} \tag{5.21}$$

$$\textbf{Planting Costs} = \text{Graphical function.} \tag{5.22}$$

Financial Supports for Planting represents the unit financial support given by the governmental institutions in return to unit planting operations (i.e. financial support paid to the farmers for each tree that they plant). Planting Costs represent the unit cost of planting operations. Since financial support and cost values are subject to change over time, especially from one harvest season to another, graphical functions are used. In order to gather these graphical functions, historical data analysis and data collected from the stakeholders can be utilized.

$$\textbf{Reference Financial Supports for Planting} = \text{Constant.} \tag{5.23}$$

$$\textbf{Reference Fruit Price} = \text{Constant.} \tag{5.24}$$

$$\textbf{Reference Planting Costs} = \text{Constant.} \tag{5.25}$$

$$\textbf{Reference Tree Stock Level} = \text{Constant.} \tag{5.26}$$

Reference Financial Supports for Planting, Reference Fruit Price, Reference Planting Costs and Reference Tree Stock Level are reference levels used for decision making. In the generic model, it is assumed that reference levels in planting module do not change rapidly and assumed to be constant. Depending on the problem setting, reference variables sometimes take the value of the corresponding variable at t = 0 (i.e. Reference Fruit Price can take the value of Fruit Price at t=0). In a more rapidly changing problem settings, reference levels can adapt and update themselves with the realizations of the corresponding variable.

$$\textbf{Sensitivity of Tree Stocks to Financial Supports} = \text{Constant} > 0. \tag{5.27}$$

$$\textbf{Sensitivity of Tree Stocks to Fruit Price} = \text{Constant} > 0. \tag{5.28}$$

$$\textbf{Sensitivity of Tree Stocks to Planting Costs} = \text{Constant} < 0. \tag{5.29}$$

Tree Stock is assumed to respond to changes in Financial Supports, Fruit Price and Planting Costs. Sensitivity of Tree Stock to Financial Supports, Sensitivity of Tree Stock to Fruit Price and Sensitivity of Tree Stock to Planting Costs represent the strength of these effects. If a sensitivity value is equal to 0, then a change in the corresponding variable does affect the tree inventory at all. If a sensitivity value is equal to 1, then the tree inventory is perfectly adjusted with respect to relative change of the corresponding variable.

5.5 Harvesting Module

Depending on the characteristics of the agricultural commodity, fruits on the bearing trees are collected during every harvest season. A share of fruits collected is processed in order to obtain bulk food, while the rest may be used in other forms depending on the characteristics of the agricultural commodity. Slightly different than the actual harvest amount, perceived fruit harvest amount is formed and updated during the harvest season. Stock and flow structure for Harvesting can be seen in Figure 5.3.

$$\textbf{Harvest Amount (t)} = \text{Harvest Amount (t - dt) + (Harvest Rate - Usage Rate) * dt.} \tag{5.30}$$

Harvest Amount variable does not represent a physical stock of fruits or plants harvested, it is an information stock which keeps the accumulation of fruit or plant harvest quantity during the corresponding season. Harvest Amount increases with Harvest Rate and decreases with Usage Rate, where Harvest Rate is positive only during the harvest season and Usage Rate is only positive just before the harvest season (to reset the Harvest Amount stock just before the next harvest season).

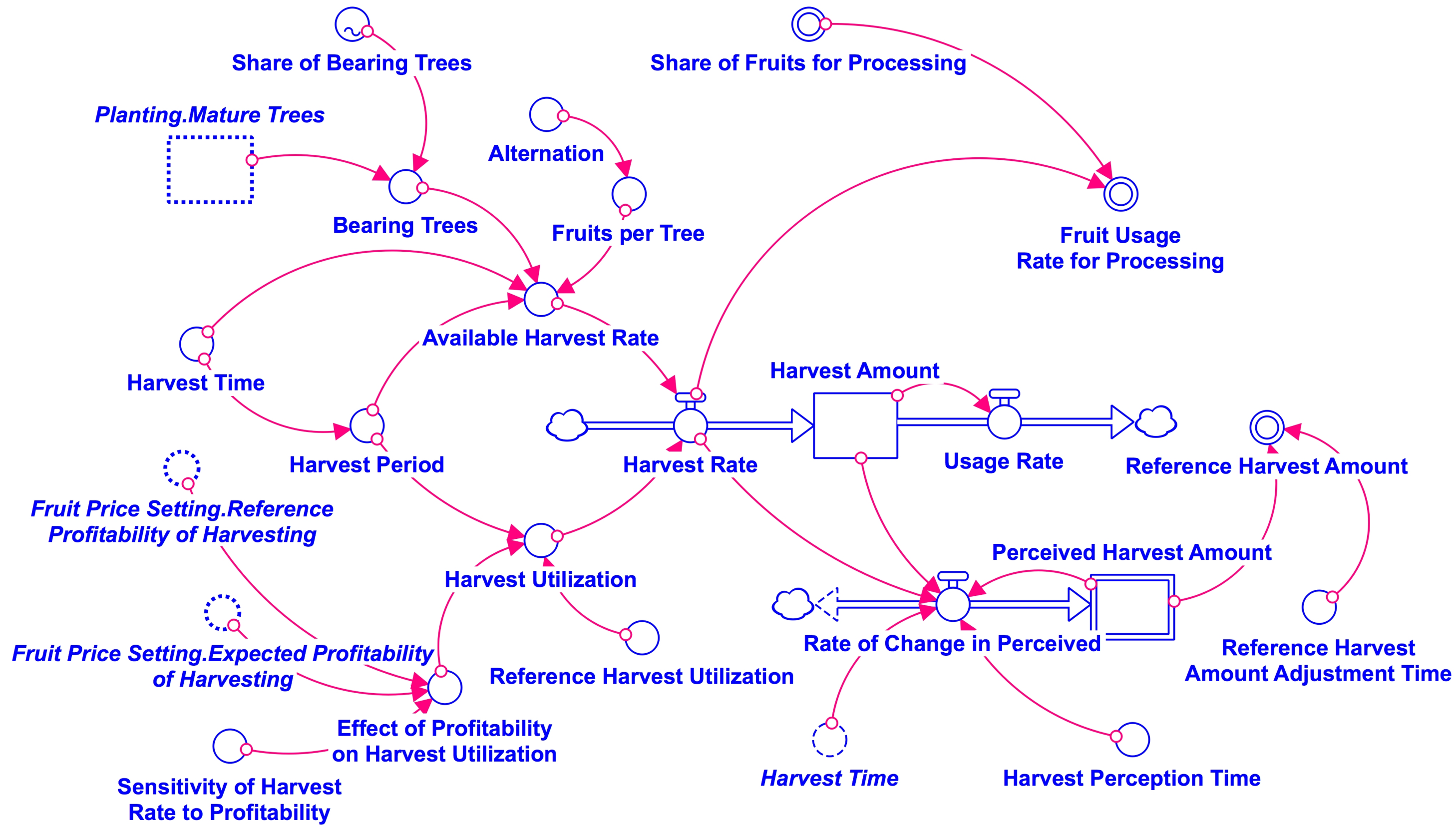

Figure 5.3: Stock and Flow Diagram of the Harvesting Module

$$\textbf{Harvest Rate} = \text{Available Harvest Rate * Harvest Utilization.} \tag{5.31}$$

Harvest Rate is the product of Available Harvest Rate and Harvest Utilization.

$$\textbf{Usage Rate} = \text{IF TIME MOD 12 = 12-DT THEN Harvest Amount/DT ELSE 0.} \tag{5.32}$$

As it is mentioned before, Harvest Amount is not a physical stock; it is only an information stock to keep the total harvest amount for the whole harvest season. Usage Rate is equal to the magnitude of the accumulated Harvest Amount just before the harvest season and every other time it is equal to 0. Usage Rate acts as a resetting variable for harvest amount.

$$\textbf{Available Harvest Rate} = \text{(Harvest Period * Bearing Trees * Fruits per Tree)}$$
$$\text{/ Harvest Time.} \tag{5.33}$$

During the harvest period, fruits on the bearing trees are collected and available harvest rate is calculated as available fruits on the bearing trees divided by the harvest time.

$$\textbf{Harvest Utilization} = \text{MIN (Harvest Period * Reference Harvest Utilization}$$
$$\text{* Effect of Profitability on Harvest Utilization, 1)} \tag{5.34}$$

During the harvest period, harvest utilization is calculated with the reference harvest utilization multiplied by effect of profitability. Since utilization level can not be higher than 1, the function is bounded above.

$$\textbf{Harvest Period} = \text{IF ((TIME MOD 12)} \geq \text{0 AND (TIME MOD 12)} < \text{Harvest}$$
$$\text{Time) THEN 1 ELSE 0.} \tag{5.35}$$

Harvest period variable is a logical expression which checks that whether TIME in model is within the harvest period or not. Time unit of our model is months and the expression above indicates that, harvest period in each year is between months 0 and Harvest Time.

$$\textbf{Harvest Time} = \text{Constant.} \tag{5.36}$$

Harvest time, which is specific to the commodity selected, is the average time period required for all available fruits to be collected.

$$\textbf{Bearing Trees} = \text{Mature Trees * Share of Bearing Trees} \tag{5.37}$$

Bearing trees is the multiplication of mature trees and share of bearing trees.

Share of Bearing Trees $=$ Constant. (5.38)

Fruits per Tree $=$ Alternation * FPT1 + (1 - Alternation) * FPT0. (5.39)

Depending on the characteristics of the commodity, Share of Bearing Trees and Fruits per Tree variables may be constant, random variables or graphical functions that their value change from one season to another. For the generic agricultural value chain model, share of bearing trees is defined as a constant which is given to the model as an exogenous variable.

Fruits per Tree takes different values for each commodity and alter from one season to another. Yet, for some commodities, fruits per tree follows a meaningful pattern in consecutive years. In "up years" when Alternation is equal 1, the average number of fruits per bearing tree is higher than in "down years" when Alternation is equal to 0. FTP1 represents the average fruits per tree in "up years" whereas FTP0 represents the average fruit per tree in "down years". Hence, Fruits per Tree is defined as a function depending on the Alternation Effect.

Alternation $=$ IF ((TIME MOD 24) $\geq$ 0 AND (TIME MOD 24) $<$ 12)
THEN 1 ELSE 0. (5.40)

Alternation represents the "up year - down year" behavior of the fruits on the trees. Hence, this variable is not constant and goes up and down consecutively.

Reference Harvest Utilization = Constant. (5.41)

Reference harvest utilization represents the normal harvest utilization for a commodity and it is assumed to be constant which is smaller than or equal to 1.

Effect of Profitability on Harvest Utilization $=$ (Expected Profitability of Harvesting / Reference Profitability of Harvesting) ^ Sensitivity of Harvest Utilization to Profitability. (5.42)

Effect of Profitability on Harvest Utilization is formulated with the exponential effect function structure explained in Appendix A. Depending on the relative value of the expected profitability of harvesting to reference profitability of harvesting, effect of profitability on harvest utilization take on values higher than or smaller than 1.

$$\textbf{Sensitivity of Harvest Utilization to Profitability} = \text{Constant.} \tag{5.43}$$

Harvest Utilization is assumed to respond to changes in expected profitability of harvesting operations. Sensitivity of harvest utilization to profitability represents the strength of this effect. If sensitivity of harvest utilization to profitability is equal to 0, then a change in the expected profitability does not affect the harvest utilization at all. If sensitivity of harvest utilization to profitability is equal to 1, then the harvest utilization is perfectly adjusted with respect to relative change of the expected profitability.

Perceived Harvest Amount (t) = Perceived Harvest Amount (t - dt)
+ (Rate of Change in Perceived Harvest Amount) * dt. (5.44)

Similar to Harvest Amount, Perceived Harvest Amount also does not represent a physical stock; it is an information stock which keeps the perception of stakeholders on the accumulation of fruit or plant harvest quantity during the corresponding season. Perceived Harvest Amount changes with Rate of Change in Perceived Harvest Amount.

Rate of Change in Perceived Harvest Amount =
IF TIME MOD 12 $\geq$ 0 AND TIME MOD 12 < Harvest Time
THEN ((Harvest Amount + (Harvest Time - TIME MOD 12) * Harvest Rate) -
Perceived Harvest Amount) / Harvest Perception Time ELSE
(Harvest Amount - Perceived Harvest Amount) / Harvest Perception Time(5.45)

During the harvest season, stakeholders have limited access on the actual harvest amount, hence their perceptions on the total harvest amount are updated depending on the limited information of the harvest. After the harvest season is completed, they obtain more and more information each day and update their perception towards the total realized harvest amount.

$$\textbf{Harvest Perception Time} = \text{Constant.} \tag{5.46}$$

Harvest Perception Time indicates the average time required for decision makers to realize and adjust their perception on the harvest amount and hence change their price setting decisions.

$$\textbf{Fruit Usage Rate for Processing} = \text{Harvest Rate * Share of Fruits for Processing.} \tag{5.47}$$

Since it is assumed that the commodity in focus is not storable in fruit form but storable in processed bulk food form, harvested fruits are processed almost immediately with respect to time unit of the model. Hence, fruit usage rate for processing is defined as the direct multiplication of harvest rate and share of fruits for processing.

$$\textbf{Share of Fruits for Processing} = \text{Constant.} \tag{5.48}$$

All of the harvested fruits may not be processed in order to obtain bulk food: one portion of them may be consumed as fresh fruits, another portion may be used as raw material in other supporting industries and only one portion is processed, turned into bulk food and stored. The share of fruits for processing depends on the characteristics of the agricultural commodity and it takes a value between 0 and 1. For the generic agricultural value chain model, share of fruits for processing is defined as a constant which is given to the model as an exogenous variable.

$$\begin{aligned}&\textbf{Reference Harvest Amount} = \text{SMTH1(Perceived Harvest Amount,}\\&\text{Reference Harvest Amount Adjustment Time).}\end{aligned} \tag{5.49}$$

In order to facilitate decision making, stakeholders have an implicitly normal, reference level of yearly harvest amount. Reference harvest amount is updated with their harvest perceptions and the adjustment time to update their reference levels. Reference Harvest Amount is modeled with a typical first-order information delay structure; the details of common delay structures can be seen in Appendix A. As the harvest amount is realized during the season, stakeholders compare the reference harvest amount with their perceived harvest amount and make their fruit price setting decisions accordingly.

$$\textbf{Reference Harvest Amount Adjustment Time} = \text{Constant.} \tag{5.50}$$

Reference Harvest Amount Adjustment Time indicates the average time required for decision makers to realize and adjust their perception on the reference harvest amount and hence change their fruit price setting decisions.

5.6 Food Processing Module

In Food Processing Module, Fruit is processed (extracted, blended, heated etc. depending on its characteristics) and transformed into Bulk Food. Bulk Food is then accumulated in inventory, which is the Processed Bulk Food Inventory kept in large depots or tanks. This inventory can be seen as the WIP (Work-in-Process) inventory for the food which is not yet ready for industrial sale. Stock and flow structure for Food Processing Module can be seen in Figure 5.4.

Processed Bulk Food Inventory (t) = Processed Bulk Food Inventory (t - dt) + (Food Processing Rate - Bulk Food Domestic Usage Rate - Bulk Food Export Rate) * dt. (5.51)

Processed Bulk Food Inventory accumulates with Food Processing Rate and diminishes with both Bulk Food Domestic Usage Rate and Bulk Food Export Rate.

Food Processing Rate = Fruit Usage Rate for Processing * Processing Yield * Process Utilization. (5.52)

Fruit which is available to be used for processing is converted into bulk food with a processing yield and with a process utilization level which depends on the profitability of the processing operations.

Processing Yield = Constant. (5.53)

Processing Yield is the multiplier indicating how much bulk food is obtained when one unit of fruit is processed. Depending on the characteristics of the commodity, yield may be a constant, a random variable or a graphical function that changes from one season to another. For the generic agricultural commodity model, it is assumed that processing yield is a constant which is given to the model as an exogenous variable.

Process Utilization = MIN (Effect of Profitability on Processing Utilization * Reference Process Utilization, 1). (5.54)

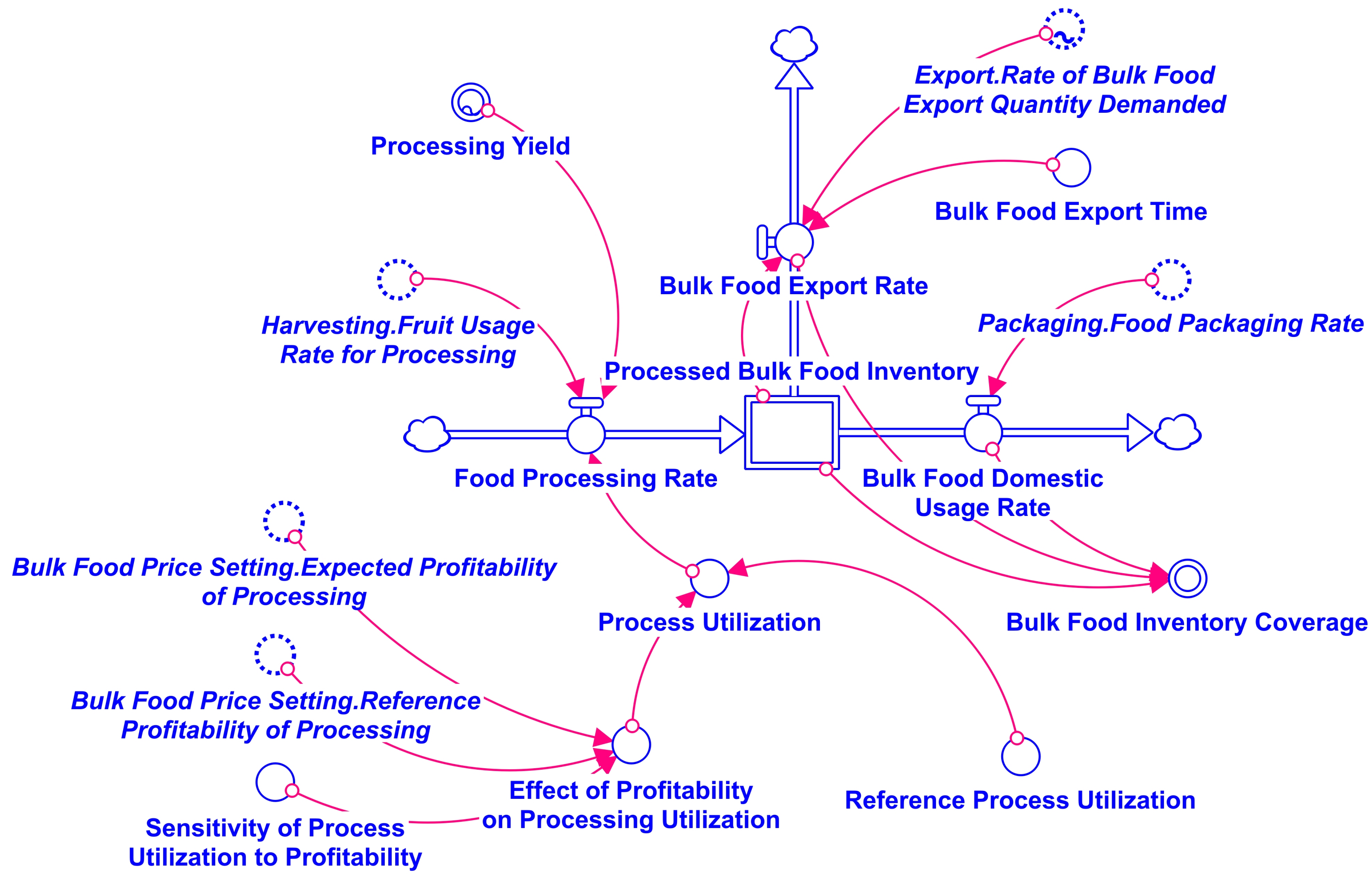

Figure 5.4: Stock and Flow Diagram of the Processing Module

Process Utilization is assumed to respond to changes in expected profitability of food processing operations. Hence, process utilization is calculated with the reference utilization multiplied by effect of profitability. Since utilization level can not be higher than 1, the function is bounded above.

Effect of Profitability on Processing Utilization $=$ (Expected Profitability of Processing / Reference Profitability of Processing) ^ Sensitivity of Process Utilization to Profitability. (5.55)

Effect of Profitability on Processing Utilization is formulated as exponential effect function as explained in Appendix A. Depending on the relative value of the expected profitability of processing to reference profitability of processing, effect of profitability on process utilization takes on values higher than or smaller than 1.

Reference Process Utilization = Constant. (5.56)

Reference process utilization represents the normal process utilization for a commodity and it is assumed to be constant which is smaller than or equal to 1.

Sensitivity of Process Utilization to Profitability = Constant $>$ 0. (5.57)

Sensitivity of process utilization to profitability represents the strength of the effect of profitability on processing utilization. If sensitivity of process utilization to profitability is equal to 0, then a change in the expected profitability does not affect the process utilization at all. If sensitivity of process utilization to profitability is equal to 1, then the process utilization is perfectly adjusted with respect to relative change of the expected profitability.

Bulk Food Domestic Usage Rate = Food Packaging Rate. (5.58)

Bulk Food Domestic Usage Rate is equal to Food Packaging Rate. Packaging food and accumulating it in the Packaged Food Inventory indicate the usage of bulk food in the Processed Bulk Food Inventory. Food Packaging Rate is formulated as MIN (Available Packaging Rate, Desired Packaging Rate), which is bounded by the available Processed Bulk Food Inventory on hand. Hence, Bulk Food Domestic Usage Rate is also bounded.

Bulk Food Export Rate $=$ MIN (Rate of Bulk Food Export Quantity Demanded, Processed Bulk Food Inventory / Bulk Food Export Time). (5.59)

Similar to Bulk Food Domestic Usage Rate, Bulk Food Export Rate is also bounded by the available Processed Bulk Food Inventory on hand.

Bulk Food Export Time = Constant. (5.60)

Bulk Food Export Time is the average time required for the transportation of the products from bulk food inventory to the export destination.

Bulk Food Inventory Coverage = Processed Bulk Food Inventory
/ (Bulk Food Domestic Usage Rate + Bulk Food Export Rate). (5.61)

Bulk Food Inventory Coverage is the length of time that is obtained as the ratio of Processed Bulk Food Inventory available to total of its corresponding outflow rates, i.e., summation of Bulk Food Domestic Usage Rate and Bulk Food Export Rate.

5.7 Packaging Module

Bulk food is packaged and accumulated in Packaged Food Inventory depending on the producers' and packaging companies' Food Packaging Rate decision on "How much of Processed Bulk Food Inventory would be packaged and be ready to for the end consumers?". This type of second inventory is actually the stocks in the warehouses or shelves of the wholesalers' and retailers' available for selling. Packaged Food Inventory increases with Food Packaging Rate and diminishes with Domestic Consumption Rate and Packaged Food Export Rate.

In our model, Food Packaging Rate is determined by comparing the Available Packaging Rate and Desired Packaging Rate. In the reviewed literature, Capacity Utilization variable is used to determine the short term supply level instead of our Desired Packaging Rate type of variable. In Sterman (2000)'s Generic Commodity Model, Indicated Capacity Utilization is a dependent variable on Expected Markup Ratio. Then, Production Capacity is multiplied with the Indicated Capacity Utilization in order to obtain Indicated Production Rate. This formulation is more appropriate for manufacturing systems where the production capacity is the binding constraint and the raw material for the production is assumed to be available (i.e. infinite supply of raw materials). Yet, in an agricultural commodity model, the crop or the processed food quantity turns out to be the binding constraint and our Bulk Food Inventory acts similar to Production Capacity. Hence, Available Packaging Rate in our model is dependent on Available Bulk Food Inventory.

Available Bulk Food Inventory has an unique behavior mode: It tends to monotonically increase during the harvest season (between T1 and T2) and monotonically decrease between two harvest seasons (after T2 to the next year's T1). Hence, a "normal, expected, desired etc." capacity utilization (i.e. inventory utilization) level cannot be suggested. Yet, one can come up with a Reference Packaging Rate for each harvest year, and depending on the Expected Profitability of Packaging, a Desired Packaging Rate can be calculated. Then, the Desired Packaging Rate indicates the short term supply curve. The details of the formulation and variables are given below.

Stock and flow structure for the Packaging Sector can be seen in Figure 5.5.

Packaged Food Inventory (t) = Packaged Food Inventory (t - dt)
+ (Food Packaging Rate - Domestic Consumption Rate
- Packaged Food Export Rate) * dt. (5.62)

Packaged Food Inventory accumulates with Food Packaging Rate and diminishes with Domestic Consumption Rate and Packaged Food Export Rate.

Food Packaging Rate = MIN (Available Packaging Rate, Desired Packaging Rate) (5.63)

Food Packaging Rate takes the minimum value of Available Packaging Rate and Desired Packaging Rate. Desired Packaging Rate represents the short term supply function, i.e. desired level of production for a given level of profitability, whereas Available Production Rate constraints the Food Packaging Rate with the available bulk inventory.

Packaged Food Export Rate = MIN (Packaged Food Export Quantity Demanded, Packaged Food Inventory / Packaged Food Export Time) (5.64)

Domestic Consumption Rate = MIN (Demand, Packaged Food Inventory / Distribution and Retailing Time) (5.65)

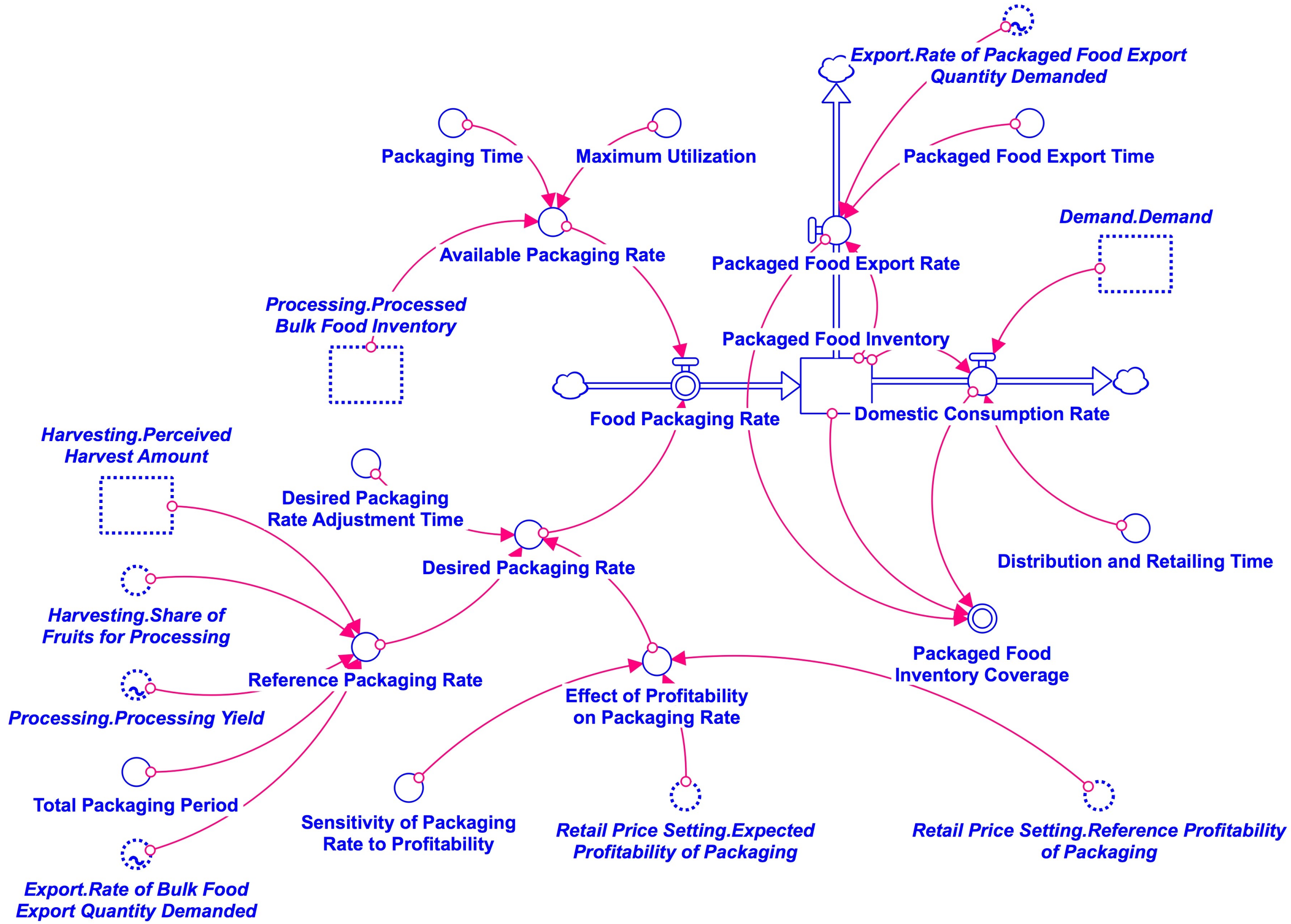

Figure 5.5: Stock and Flow Diagram of the Packaging Module

Packaged Food Export Rate and Domestic Consumption Rate are the outflows of Packaged Food Inventory. Hence, they are both constrained by the available Packaged Food Inventory on hand.

Available Packaging Rate = (Processed Bulk Food Inventory / Packaging Time) * Maximum Utilization. (5.66)

Available Packaging Rate is determined by the available inventory in the upper node of the supply chain, i.e. Processed Bulk Food Inventory divided by Packaging Time. In order to represent the efficiency and utilization level of packaging process, Maximum Utilization coefficient is used.

Desired Packaging Rate = SMTH1(Reference Packaging Rate * Effect of Profitability on Packaging Rate, Desired Packaging Rate Adjustment Time). (5.67)

Desired Packaging Rate acts as a short term supply function which increases with the expected profitability of packaging. Desired supply level does not change immediately; i.e., it takes time for producers to realize the profitability of current operations. Hence, the delay in the adjustment of Desired Packaging Rate is formulated as a first-order information delay structure with the help of built-in SMTH function of Stella; the details of common delay structures can be seen in Appendix A.

A similar structure can be seen in Generic Commodity Model presented in Sterman (2000), in Capacity Utilization formulation as below:

Capacity Utilization = SMTH1 (Indicated Capacity Utilization, Utilization Adjustment Time).

Distribution and Retailing Time = Constant. (5.68)

Packaged Food Export Time = Constant. (5.69)

Packaging Time = Constant. (5.70)

These time constants represent the average time units required for the physical flow of the product along the supply chain. Distribution and Retailing Time is the average time required for packaged product to reach the consumers. Packaged Export Time is the average time required for the transportation of the products from packaged food inventory to the export destination. Packaging Time is the average time required to transform the processed bulk food to packaged food.

$$\textbf{Maximum Utilization} = \text{Constant} \leq 1. \tag{5.71}$$

During the packaging process, producers and packaging companies may not fully utilize the bulk food due several losses or inefficiencies. Hence, Maximum Utilization is used as a coefficient which is expected to be equal to or smaller than 1.

Reference Packaging Rate = (Perceived Harvest Amount * Processing Yield * Share of Fruits for Processing) / Total Packaging Period - SMTH1 (Rate of Bulk Food Export Quantity Demanded, 12). (5.72)

Reference Packaging Rate is the normal packaging rate desired by the producers or the packaging companies at the normal or reference profitability of packaging operations. It is calculated depending on the harvest amount perceptions of the decision makers: Perceived Harvest Amount times Processing Yield times Share of Fruits for Processing gives the perceived bulk food amount for the whole harvest year. Then, it is divided by Total Packaging Period to find an expectation on available bulk food amount for one packaging period. Since one portion of the bulk food available is used by the bulk food export, the rest gives the Reference Packaging Rate.

$$\textbf{Total Packaging Period} = \text{Constant}. \tag{5.73}$$

Total Packaging Period represents the time period in a year when the packaging operations are done. For instance, if the time unit of the model is months and packaging operations are done in every month of the year, then Total Packaging Period is 12 months.

Effect of Profitability on Packaging Rate = (Expected Profitability of Packaging / Reference Profitability of Packaging) ^ Sensitivity of Packaging Rate to Profitability. (5.74)

Effect of Profitability on Packaging Rate is formulated as an exponential effect function as explained in Appendix A. As soon as the Expected Profitability of Packaging is equal to Reference Profitability of Packaging, then Effect of Profitability on Packaging Rate is equal to 1. Otherwise, depending on the relative magnitude between the variable and its reference value, effect takes higher or lower values than 1.

$$\textbf{Sensitivity of Packaging Rate to Profitability} = \text{Constant} > 0. \tag{5.75}$$

Sensitivity of Packaging Rate to Profitability stands for the elasticity of packaged food supply with respect to changes in expected profitability. In this case, it is expected to be strictly positive and its magnitude shows the strength of the relationship between Packaging Rate and Expected Profitability.

$$\textbf{Desired Packaging Rate Adjustment Time} = \text{Constant}. \tag{5.76}$$

Desired Packaging Rate Adjustment Time indicates the average time required for producers to realize and adjust their desired level of packaging rate, and hence determine their short term supply decision.

$$\begin{aligned}\textbf{Packaged Food Inventory Coverage} &= \text{Packaged Food Inventory} \\ &\text{/ (Domestic Consumption Rate + Packaged Food Export Rate)}\end{aligned} \tag{5.77}$$

Packaged Food Inventory Coverage is the time units obtained with the ratio of Packaged Food Inventory available to total of its corresponding outflow rates, i.e., summation of Domestic Consumption Rate and Packaged Food Export Rate.

5.8 Demand Module

Demand Module represents the domestic demand for the corresponding agricultural commodity. Demand is modeled to be dependent on the Consumer Price, the Substitute Price and other external factors such as Income (GDP), Market Trend and Population. Stock and flow structure for Demand can be seen in Figure 5.6.

$$\textbf{Demand (t)} = \text{Demand (t - dt) + (Rate of Change in Demand) * dt}. \tag{5.78}$$

Demand, i.e., quantity demanded per time, is the only stock defined in Demand sector. Demand increases or decreases with Rate of Change in Demand.

$$\begin{aligned}\textbf{Rate of Change in Demand} &= \text{(Indicated Industry Demand - Demand)} \\ &\text{/ Demand Adjustment Time}.\end{aligned} \tag{5.79}$$

Rate of Change in Demand is the rate of change in quantity demanded per time. It takes on a positive value if Indicated Industry Demand is higher than Demand, and takes on a negative value if Indicated Industry Demand is lower than Demand.

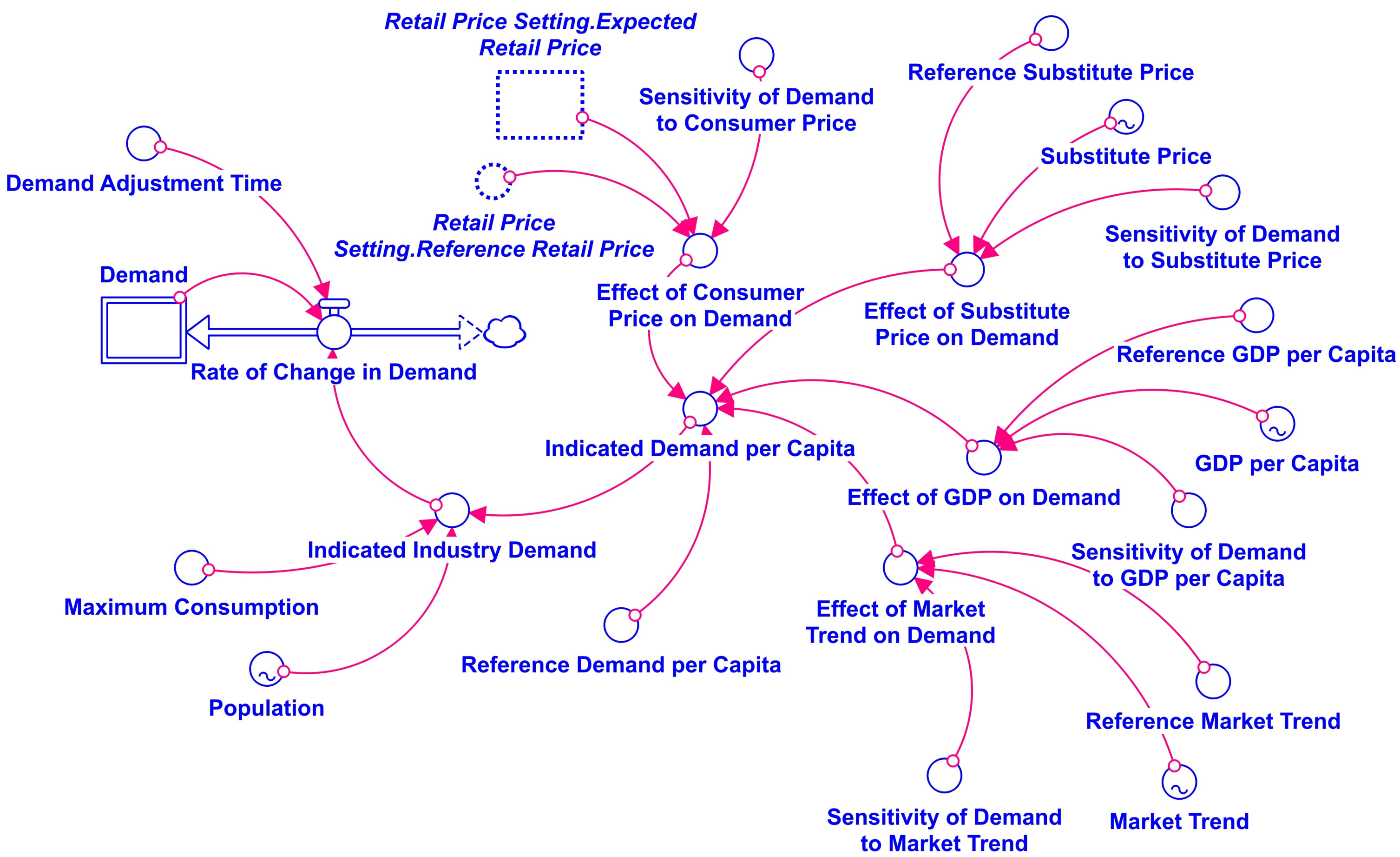

Figure 5.6: Stock and Flow Diagram of the Demand Module

$$\textbf{Demand Adjustment Time} = \text{Constant.} \tag{5.80}$$

Industry Demand adjusts with a delay to the demand indicated by commodity price, substitute price and other relevant factors. Demand Adjustment Time indicates the length of that delay and determines the magnitude of Rate of Change in Demand. It is assumed to be a constant value for the time horizon of the model.

$$\begin{aligned}&\textbf{Indicated Industry Demand} = \text{MIN (Maximum Consumption,}\\&\text{(Indicated Demand per Capita * Population)).}\end{aligned} \tag{5.81}$$

Indicated Industry Demand is the minimum of Maximum Consumption and product of Indicated Demand per Capita and Population.

$$\textbf{Maximum Consumption} = \text{Constant.} \tag{5.82}$$

Maximum Consumption is the upper bound for the Indicated Industry Demand. It is supposed to be determined with relevant data analysis and expert opinion. It is assumed to be a constant value for the time horizon of the model.

$$\textbf{Population} = \text{Graphical Function.} \tag{5.83}$$

It is expected that an increase (a decrease) in population leads to an increase (a decrease) in Indicated Industry Demand. For population data, statistical reports published by institutions can be used as reference. It is assumed that population changes over time for the time horizon of the model and it is given to the model as an input in the form of a graphical function.

$$\begin{aligned}&\textbf{Indicated Demand per Capita} = \text{Reference Demand per Capita * Effect of}\\&\text{Consumer Price on Demand * Effect of Substitute Price on Demand}\\&\text{* Effect of GDP on Demand * Effect of Market Trend on Demand.}\end{aligned} \tag{5.84}$$

Indicated Demand per Capita is modeled as dependent on changes in consumer price of the corresponding agricultural commodity, consumer price of the major substitute commodity, income and market trend. It is assumed that Indicated Demand per Capita increases with Substitute Price, Income and Market Trend, and decreases with Consumer Price of the corresponding agricultural commodity.

Depending on the problem definition and model boundary selection, other external effects can be used in order to describe the demand function. Yet, the analytical structure would be similar to the one explained in here.

Reference Demand per Capita = Constant. (5.85)

Reference Demand per Capita represents the normal quantity demanded per capita for the commodity. It can be taken as the actual quantity demanded per capita at t = 0.

Effect of Consumer Price on Demand = (Retail Price / Reference Retail Price) ^ Sensitivity of Demand to Retail Price. (5.86)

Effect of Substitute Price on Demand = (Substitute Price / Reference Substitute Price) ^ Sensitivity of Demand to Substitute Price. (5.87)

Effect of GDP on Demand = (GDP per Capita / Reference GDP per Capita) ^ Sensitivity of Demand to GDP per Capita. (5.88)

Effect of Market Trend on Demand = (Market Trend / Reference Market Trend) ^ Sensitivity of Demand to Market Trend. (5.89)

Effect of Consumer Price, Substitute Price, GDP and Market Trend on Demand variables are formulated as exponential effect functions as explained in Appendix A. As soon as the corresponding variable is equal to its reference value, then its effect is equal to 1.

Substitute Price = Graphical function. (5.90)

GDP per Capita = Graphical function. (5.91)

Market Trend = Graphical function. (5.92)

It is assumed that Substitute Price, GDP per Capita and Market Trend variables change over time within the time horizon of the model and they are given to the model as exogenous inputs in the form of a graphical functions. For substitute price, retail price of the one major agricultural commodity is used. For both GDP per capita and substitute price data, statistical reports published by institutions can be used as reference, as in the case of population. Market Trend is accepted to be an indicator to represent the trend in the domestic market for consumption. For Market Trend data, the magnitude of informative or advertorial activities about the corresponding agricultural products can be analyzed. Also, trend indicators in online databases, such as Google Trends can be used.

$$\textbf{Reference Retail Price} = \text{Constant.} \tag{5.93}$$

$$\textbf{Reference Substitute Price} = \text{Constant.} \tag{5.94}$$

$$\textbf{Reference GDP per Capita} = \text{Constant.} \tag{5.95}$$

$$\textbf{Reference Market Trend} = \text{Constant.} \tag{5.96}$$

Reference Retail Price, Substitute Price, GDP per Capita and Market Trend are the reference values for their corresponding parameters and the values of Retail Price, Substitute Price, GDP per Capita and Market Trend at t = 0 can be used respectively.

$$\textbf{Sensitivity of Demand to Retail Price} = \text{Constant} < 0. \tag{5.97}$$

$$\textbf{Sensitivity of Demand to Substitute Price} = \text{Constant} > 0. \tag{5.98}$$

$$\textbf{Sensitivity of Demand to GDP per Capita} = \text{Constant} > 0. \tag{5.99}$$

$$\textbf{Sensitivity of Demand to Market Trend} = \text{Constant} > 0. \tag{5.100}$$

Sensitivity of Demand to Retail Price, Substitute Price, GDP per Capita and Market Trend variables stand for the elasticity of demand with respect to changes in corresponding variable. Depending on the relationship between Demand and the changing variable, Sensitivity variables take positive or negative values. Additionally, their magnitude shows the strength of the relationship between Demand and the changing variable.

5.9 Export Module

Export module consists of exogenous quantity and price information of Packaged Food Export and Bulk Food Export.

$$\textbf{Rate Packaged Food Export Quantity Demanded} = \text{Graphical.} \tag{5.101}$$

$$\textbf{Rate of Bulk Food Export Quantity Demanded} = \text{Graphical.} \tag{5.102}$$

$$\textbf{Packaged Food Export Price} = \text{Graphical.} \tag{5.103}$$

$$\textbf{Bulk Food Export Price} = \text{Graphical.} \tag{5.104}$$

Four major variables in this module, Rate of Packaged Food Export Quantity Demanded, Rate of Bulk Food Export Quantity Demanded, Packaged Food Export Price and Bulk Food Export Price are graphical functions of time.

Reference Bulk Food Export Price = SMTH1(Bulk Food Export Price, Reference Bulk Export Price Adjustment Time.) (5.105)

Reference Packaged Food Export Price = SMTH1(Packaged Food Export Price, Reference Packaged Export Price Adjustment Time.) (5.106)

Reference Bulk Food Export Price and Reference Packaged Food Export Price values adjust themselves with first-order delay structures and exponential smoothing functions according to realizations in prices. The details of common delay structures can be seen in Appendix A.

Reference Packaged Export Price Adjustment Time = Constant. (5.107)

Reference Bulk Export Price Adjustment Time = Constant. (5.108)

Reference Bulk Export Price Adjustment Time and Reference Packaged Export Price Adjustment Time indicates the average time values required for decision makers to realize and adjust their perception on the reference bulk food and packaged food export prices and hence change their price setting decisions in the domestic market.

5.10 Fruit Price Setting Module

Fruit price emerges depending on the harvesting costs, expectations on fruit harvest amount and expected price of bulk food. Stock and flow structure for Fruit Price Setting can be seen in Figure 5.7.

Expected Fruit Price (t) = Expected Fruit Price (t - dt) + (Rate of Change in Expected Fruit Price) * dt. (5.109)

Expected Fruit Price increases or decreases with Rate of Change in Expected Fruit Price.

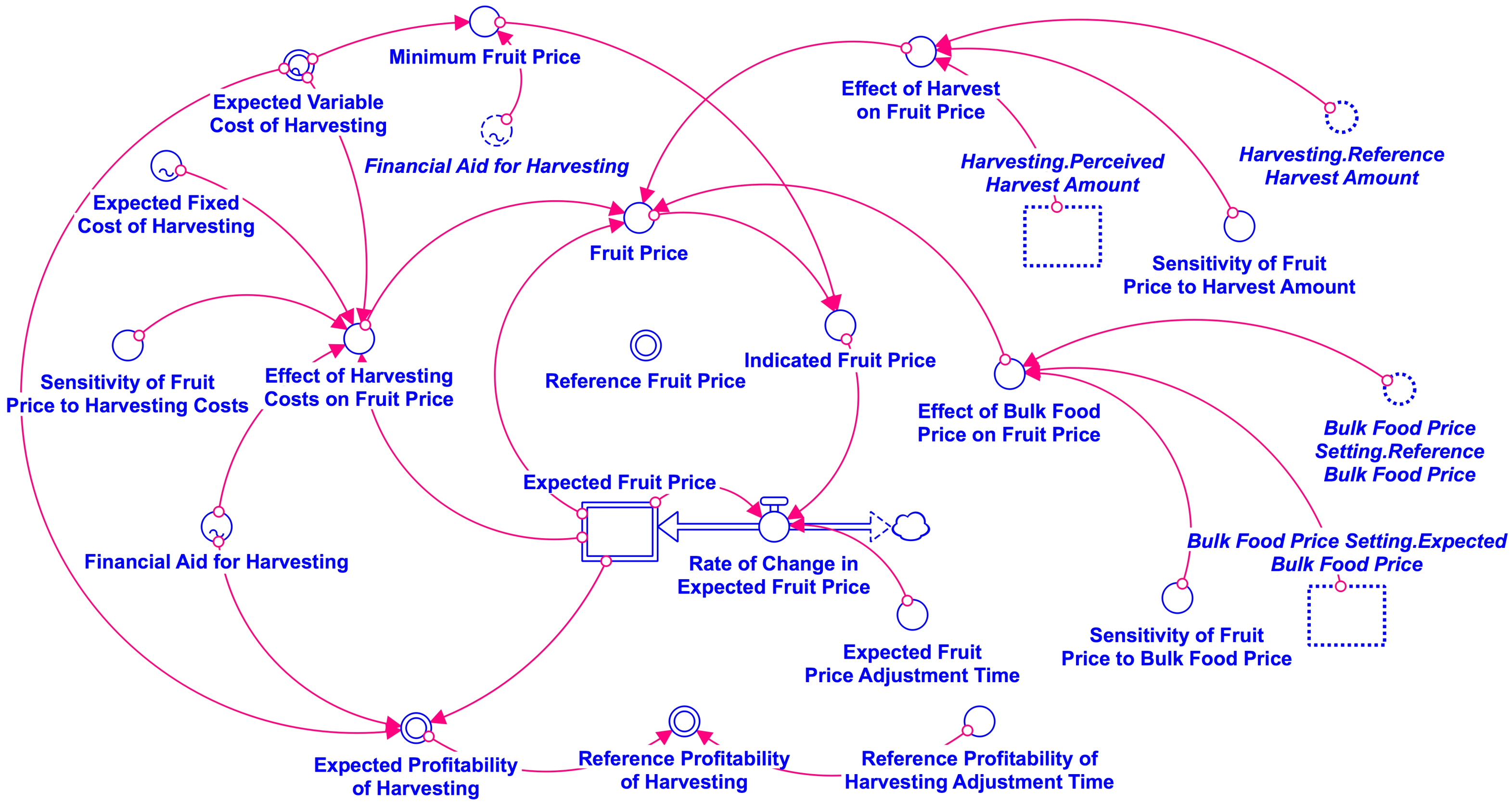

Figure 5.7: Stock and Flow Diagram of the Fruit Price Setting Module

Rate of Change in Expected Fruit Price = (Indicated Fruit Price
- Expected Fruit Price) / Expected Fruit Price Adjustment Time. (5.110)

Rate of Change in Expected Fruit Price takes on a positive value if Indicated Fruit Price is higher than Expected Fruit Price, and takes on a negative value if Indicated Fruit Price is lower than Expected Fruit Price.

Indicated Fruit Price = MAX (Minimum Fruit Price, Fruit Price). (5.111)

Indicated Fruit Price is the maximum of Minimum Fruit Price and Fruit Price.

Expected Fruit Price Adjustment Time = Constant. (5.112)

Expected Fruit Price is adjusted with a delay to the fruit price which is indicated by the effects of harvesting costs, expectations on fruit harvest amount and expected price of bulk food. Expected Fruit Price Adjustment Time indicates the average length of that delay and determines the magnitude of Rate of Change in Expected Fruit Price. It is assumed to be a constant value for the time horizon of the model.

Minimum Fruit Price = Expected Variable Cost of Harvesting
- Financial Aid for Harvesting. (5.113)

Fruit Price may temporarily fall below the total cost of farming and harvesting. Yet, a farmer can not operate if the unit fruit price is lower than the total unit variable cost. During the harvesting stage, there may be some financial aids given by the government or institutions in order to promote harvesting activities. Hence, minimum unit fruit price is the unit variable cost of harvesting minus relevant financial aid for harvesting per unit.

Financial Aid for Harvesting = Graphical function. (5.114)

In order to financially support the fruit harvesting operations, governments and institutions may provide financial aids for each unit of fruit harvested. These aids may alter from one season to another, and hence it is assumed to be a graphical function and exogenous variable within the time horizon of the model.

Fruit Price = Expected Fruit Price * Effect of Harvesting Costs
on Fruit Price * Effect of Harvest Amount on Fruit Price
* Effect of Bulk Food Price on Fruit Price. (5.115)

It is assumed that Fruit Price increases with harvesting costs and bulk food price, and decreases with harvest amount realized.

Effect of Harvesting Costs on Fruit Price = MAX (0, 1 + Sensitivity of Fruit Price to Harvesting Costs * (((Expected Fixed Cost of Harvesting + Expected Variable Cost of Harvesting - Financial Aid for Harvesting) / Expected Fruit Price) - 1)) (5.116)

Effect of Harvesting Costs on Fruit Price aims to adjust the price with respect to harvesting costs. In Generic Commodity Market Model by Sterman (2000), Effect of Costs on Price is formulated as:

Effect of Costs on Price = 1 + Sensitivity of Price to Costs * (((Expected Production Costs) / Expected Price) - 1)

where Expected Production Costs includes both the Expected Fixed Costs and Expected Variable Costs.

In our modified Effect of Harvesting Costs on Fruit Price formulation, if all relevant harvesting costs minus financial supports are higher than the Expected Fruit Price, then it takes on a value higher than 1; else, it takes on a value lower than 1. For the effect function not to take negative values in extreme conditions, it is bounded below with 0.

Effect of Harvest on Fruit Price = (Perceived Harvest Amount / Reference Harvest Amount) ^ Sensitivity of Fruit Price to Fruit Harvest Amount. (5.117)

Effect of Harvest Amount is formulated as an exponential effect function as explained in Appendix A. Realized harvest amount has an effect on fruit price which corresponds to the effect of supply and demand balance. Just before the harvest season, stakeholders have an expected, reference level of yearly harvest amount. Depending on the relative value of the realized harvest amount with respect to the reference level, Effect of Harvest Amount on Fruit Price emerges. If “it is a good (bad) year”, then Effect of Harvest Amount on Fruit Price is expected to take value smaller (larger) than 1.

$$\textbf{Effect of Bulk Food Price on Fruit Price} = \text{(Expected Bulk Food Price} \\ \text{/ Reference Bulk Price) \^{} Sensitivity of Fruit Price to Bulk Food.} \quad (5.118)$$

Effect of Bulk Food Price on Fruit Price is formulated as an exponential effcet functions as explained in Appendix A. Depending on the relative value of the bulk food price to its reference value, the effect of bulk food price on fruit Price takes on values either higher than or smaller than 1.

$$\textbf{Sensitivity of Fruit Price to Harvesting Costs} = \text{Constant} > 0. \quad (5.119)$$

Fruit Price is assumed to respond to changes in harvesting costs. Sensitivity of Fruit Price to Harvesting Costs represents the strength of this effect. If it is equal to 0, then harvesting costs do not affect the fruit price at all. If it is equal to 1, then fruit prices are anchored to harvesting costs. In commodity markets, the response of price to costs is likely to be weak (Sensitivity of Price to Costs $<$ 1) (Sterman, 2000). In order to determine the magnitude of the sensitivity, historical data analysis and expert opinion are utilized.

$$\textbf{Expected Fixed Cost of Harvesting} = \text{Graphical function.} \quad (5.120)$$

$$\textbf{Expected Variable Cost of Harvesting} = \text{Graphical function.} \quad (5.121)$$

Expected Fixed and Variable Costs of Harvesting represent the unit fixed and variable costs in order to grow the trees and collect the fruit from the trees. Since cost values are subject to change over time, graphical functions are used instead of constants or average cost values. In order to gather these graphical functions, historical data analysis and data collected from the stakeholders are utilized.

$$\textbf{Sensitivity of Fruit Price to Harvest Amount} = \text{Constant} < 0. \quad (5.122)$$

$$\textbf{Sensitivity of Fruit Price to Bulk Food Price} = \text{Constant} > 0. \quad (5.123)$$

Fruit Price is assumed to respond to changes in realized Harvest Amount and Bulk Food Price. Sensitivity of Fruit Price to Harvest Amount and Sensitivity of Fruit Price to Bulk Food Price represent the strength of these effects. If a sensitivity value is equal to 0, then a change in the corresponding variable does not affect the fruit price at all. If a sensitivity value is equal to 1 (or -1 depending on its sign), then the fruit price is perfectly adjusted with respect to relative change of the corresponding variable.

Expected Profitability of Harvesting = MAX (0, Expected Fruit Price + Financial Aid for Harvesting - Expected Variable Cost of Harvesting) (5.124)

Expected Profitability of Harvesting is calculated in order to capture the short term profitability of current harvesting operations, i.e., the unit profit of additional one unit of fruit harvested. Financial Aid for Harvesting is a component of the profitability which supports the unit benefit of harvesting operations. Expected Variable Cost of Harvesting represents the unit operational cost. Since a stakeholder cannot operate under minimum price, Expected Profitability of Harvesting is bounded below with 0.

Reference Profitability of Harvesting = SMTH1(Expected Profitability of Harvesting, Reference Profitability of Harvesting Adjustment Time). (5.125)

Reference Profitability of Harvesting represents the normal, desired level of unit profitability by the farmers. When the profit is lower (higher) than the reference value, then its effect on harvesting operations becomes larger (smaller) than 1. Reference Profitability of Harvesting is updated with realizations on expected profitability of harvesting operations. It is formulated with the typical first-order information delay structure. The details of common delay structures can be seen in Appendix A.

Reference Profitability of Harvesting Adjustment Time = Constant. (5.126)

Reference Profitability of Harvesting Adjustment Time indicates the average time required for decision makers to realize and adjust their perception on the reference profitability of harvesting and hence change their harvest utilization decisions.

5.11 Bulk Food Price Setting Module

Bulk food price emerges depending on the bulk food processing costs, bulk food inventory coverage, international export price of bulk food and retail price of packaged food. Stock and flow structure for Bulk Food Price Setting can be seen in Figure 5.8.

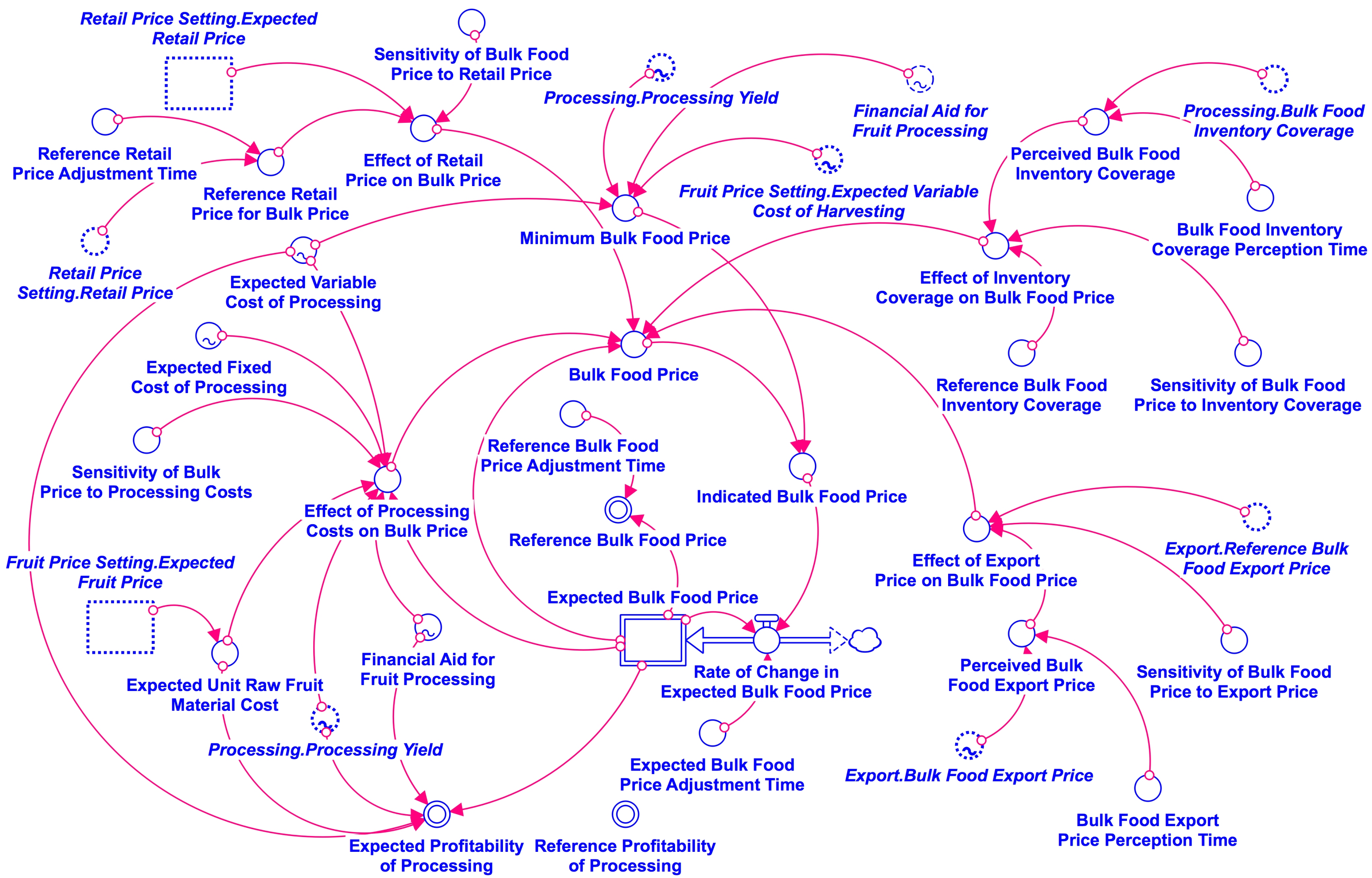

Figure 5.8: Stock and Flow Diagram of the Bulk Food Price Setting Module

Expected Bulk Food Price (t) = Expected Bulk Food Price (t - dt)

+ (Rate of Change in Expected Bulk Food Price) * dt. (5.127)

Expected Bulk Food Price increases or decreases with Rate of Change in Expected Bulk Food Price.

Rate of Change in Expected Bulk Food Price = (Indicated Bulk Food Price - Expected Bulk Food Price)/Expected Bulk Food Price Adjustment Time.(5.128)

Rate of Change in Expected Bulk Food Price takes on a positive value if Indicated Bulk Food Price is higher than Expected Bulk Food Price, and takes on a negative value if Indicated Bulk Food Price is lower than Expected Bulk Food Price.

Indicated Bulk Food Price = MAX (Minimum Bulk Food Price, Bulk Food Price). (5.129)

Indicated Bulk Food Price is the maximum of Minimum Bulk Food Price and Bulk Food Price.

Expected Bulk Food Price Adjustment Time = Constant. (5.130)

Expected Bulk Food Price adjusts with a delay to the bulk food price that is indicated by the effects of processing costs, inventory coverage, international export price, co-operative purchasing price and retail price. Expected Bulk Food Price Adjustment Time indicates the length of that delay and determines the magnitude of Rate of Change in Expected Bulk Food Price. Expected Bulk Food Price Adjustment Time is assumed to be a constant value for the time horizon of the model.

Minimum Bulk Food Price = Expected Variable Cost of Harvesting / Fruit Processing Yield + Expected Variable Cost of Processing - Financial Aid for Fruit Processing. (5.131)

Bulk Food Price may temporarily fall below the total cost of farming, fruit harvesting and processing. Yet, a producer can not operate if the unit bulk food price is lower than the total unit variable cost. Since the model is built for a value chain setting, costs accumulate along the chain. Additionally, during the processing stage, there may be some financial aids given by the government or institutions in order to promote processing activities. Hence, minimum bulk food price is the summation of unit variable costs in the previous stages plus the unit variable cost of processing minus relevant financial aid for processing. In this setting, Expected Variable Cost of Harvesting divided by Fruit Processing Yield stands for the unit variable cost for the raw material and Expected Variable Cost of Processing stands for the unit variable operational cost. Hence, lower bound of the bulk food price is set to Expected Variable Cost of Harvesting times Fruit Processing Yield plus Expected Variable Costs of Processing minus Financial Aid for Fruit Processing.

Financial Aid for Fruit Processing = Graphical function. (5.132)

In order to financially support the processing operations of fruits and help adding value to the raw commodity, governments and institutions may provide financial aids for each unit of bulk food obtained. These aids may alter from one season to another, and hence it is assumed to be graphical function and exogenous variable within time horizon of the model.

Bulk Food Price = Expected Bulk Food Price * Effect of Processing Costs on Bulk Price * Effect of Inventory Coverage on Bulk Food Price * Effect of Export Price on Bulk Food Price * Effect of Retail Price on Bulk Price. (5.133)

It is assumed that Bulk Food Price increases with processing costs, export price and retail price, and decreases with inventory coverage.

Reference Bulk Food Price = SMTH1 (Expected Bulk Food Price, Reference Bulk Food Price Adjustment Time). (5.134)

Reference Bulk Food Price represents the normal, reference level of unit bulk food price. Reference Bulk Food Price for decision makers is updated with realizations of expected bulk food price. It is formulated with the typical first-order information delay structure. The details of common delay structures can be seen in Appendix A.

Reference Bulk Food Price Adjustment Time = Constant. (5.135)

Reference Bulk Food Price Adjustment Time indicates the time required for decision makers to realize and adjust their perception on the reference bulk food price and hence change their fruit pricing decisions.

Effect of Processing Costs on Bulk Food Price = MAX (0, 1 + Sensitivity of Bulk Price to Processing Costs * (((Expected Unit Raw Fruit Material Cost / Processing Yield + Expected Fixed Cost of Processing + Expected Variable Cost of Processing - Financial Aid for Fruit Processing) / Expected Bulk Food Price) - 1)). (5.136)

Effect of Processing Costs on Bulk Food Price aims to adjust the price with respect to processing costs. In Generic Commodity Market Model by Sterman (2000), Effect of Costs on Price is formulated as:

Effect of Costs on Price = 1 + Sensitivity of Price to Costs * ((Expected Production Costs / Expected Price) - 1)

This formulation is built within a commodity market model where there is one price level and one level of operation costs; i.e. it is not built for a supply chain or a value chain structure. Hence, we modify the Effect of Processing Costs on Bulk Food Price accordingly. In order to reflect the chain structure, we add Expected Unit Raw Fruit Material Cost as the unit material cost and Financial Aid for Fruit Processing as a cost component that decreases the total cost for the decision maker.

In this modified Effect of Processing Costs on Bulk Food Price formulation, if all relevant production costs (material cost, processing costs and financial supports: Expected Unit Raw Fruit Material Cost / Fruit Processing Yield + Expected Fixed Cost of Processing + Expected Variable Cost of Processing - Financial Aid for Fruit Processing) are higher than the Expected Retail Price, then it takes on a value higher than 1; else, it takes on a value lower than 1. For the effect function not to take negative values in extreme conditions, it is bounded below with 0.

Effect of Inventory Coverage on Bulk Food Price = (Perceived Bulk Food Inventory Coverage / Reference Bulk Food Inventory Coverage) ^ Sensitivity of Bulk Food Price to Inventory Coverage. (5.137)

Effect of Export Price on Bulk Food Price = (Perceived Bulk Food Export Price / Reference Bulk Food Export Price) ^ Sensitivity of Bulk Food Price to Export Price. (5.138)

Effect of Retail Price on Bulk Food Price= (Expected Retail Price / Reference Retail Price for Bulk Price) ^ Sensitivity of Bulk Food Price to Retail Price. (5.139)

Effects of Inventory Coverage, Export Price and Retail Price on Bulk Food Price are formulated as exponential functions as explained in previous sections. Depending on the relative value of the corresponding variable to its reference value, effect variables take on values higher than or smaller than 1.

Sensitivity of Bulk Price to Processing Costs = Constant > 0. (5.140)

Bulk Food Price is assumed to respond to changes in processing costs. Sensitivity of Bulk Price to Processing Costs represents the strength of this effect. If it is equal to 0, then processing costs do not affect the bulk food price at all. If it is equal to 1, then bulk food prices are anchored to processing costs. In commodity markets, the response of price to costs is likely to be weak (Sensitivity of Price to Costs $<$ 1) (Sterman, 2000). In order to determine the magnitude of the sensitivity, historical data analysis and expert opinion are utilized.

Expected Unit Raw Fruit Material Cost = Expected Fruit Price. (5.141)

Expected Unit Raw Fruit Material Cost is equal to Expected Fruit Price, which acts as the unit raw material cost for the bulk food processing operations.

Expected Fixed Cost of Processing = Graphical function. (5.142)

Expected Variable Cost of Processing = Graphical function. (5.143)

Expected Fixed and Variable Costs of Processing represent the unit fixed and variable costs in order to transform the fruit harvested into the bulk processed food which is then stored in Bulk Food Inventories. Since cost values are subject to change over time, graphical functions are used instead of constants or average cost values. In order to gather these graphical functions, historical data analysis and data collected from the stakeholders are utilized.

Perceived Bulk Food Inventory Coverage $=$ SMTH1 (Bulk Food Inventory Coverage, Bulk Food Inventory Coverage Perception Time). (5.144)

Perceived Bulk Food Export Price $=$ SMTH1 (Bulk Food Export Price, Bulk Food Export Price Perception Time). (5.145)

Inventory coverage levels are not perceived by the decision makers immediately, i.e., it takes time for them to realize the ratio between available supply and demand. Additionally, international export price levels require time for decision makers to perceive and benchmark. Hence, the delays in the perception of Bulk Food Inventory Coverage and Bulk Food Export Price are formulated as first-order information delay structures with exponential smoothing functions with the help of built-in SMTH function of Stella. The details of common delay structures can be seen in Appendix A.

Bulk Food Inventory Coverage Perception Time $=$ Constant. (5.146)

Bulk Food Export Price Perception Time $=$ Constant. (5.147)

Bulk Food Inventory Coverage Perception Time and Export Price Perception Time variables indicate the average time lenghts required for decision makers to realize and adjust their perceptions on the inventory coverage level and bulk food export price level respectively and hence adjust their price setting decisions.

Reference Bulk Food Inventory Coverage $=$ IF TIME MOD 12 $\leq$ 3 THEN ((TIME MOD 12) * 3) + 1 ELSE (12 - TIME MOD 12) + 1 (5.148)

Reference Bulk Food Inventory Coverage represents the desired level of inventory coverage by the producers. When the inventory coverage is lower (higher) than the reference value, then its effect on retail price becomes higher (lower) than 1. Since bulk food inventory has a positive inflow for only Harvest Period (i.e. 3 months) in a year but has a positive outflow for all Packaging Period (i.e. 12 months) in a year, Reference Bulk Food Inventory Coverage is not a constant value. It is expected to increase during the harvest, to reach its peak level just after the harvest is completed and expected to decrease until the harvest season of the next year.

Reference Retail Price for Bulk Price $=$ SMTH1 (Retail Price, Reference Retail Price Adjustment Time). (5.149)

Reference Retail Price which is used in Bulk Price setting decisions is updated depending on the realizations of actual retail price.

$$\textbf{Reference Retail Price Adjustment Time} = \text{Constant.} \tag{5.150}$$

Reference Retail Price Adjustment Time indicates the time required for decision makers to realize and adjust their perception on the reference retail price and hence change their bulk food pricing decisions.

$$\textbf{Sensitivity of Bulk Food Price to Inv. Coverage} = \text{Constant} < 0. \tag{5.151}$$

$$\textbf{Sensitivity of Bulk Food Price to Export Price} = \text{Constant} > 0. \tag{5.152}$$

$$\textbf{Sensitivity of Bulk Food Price to Retail Price} = \text{Constant} > 0. \tag{5.153}$$

Bulk Food Price is assumed to respond to changes in Bulk Food Inventory Coverage, Export Price and Retail Price. Sensitivity of Bulk Food Price to Inventory Coverage, Sensitivity of Bulk Food Price to Export Price and Sensitivity of Bulk Food Price to Retail Price represent the strength of these effects. If a sensitivity value is equal to 0, then a change in the corresponding variable does affect the bulk food price at all. If a sensitivity value is equal to 1 (or -1 depending on its sign, then the bulk food price is perfectly adjusted with respect to relative change of the corresponding variable.

$$\begin{aligned}&\textbf{Expected Profitability of Processing} = \text{MAX (0, Expected Bulk Food Price}\\&+ \text{Financial Aid for Fruit Processing - Expected Unit Raw Fruit Material Cost}\\&/ \text{Processing Yield - Expected Variable Cost of Processing).}\end{aligned} \tag{5.154}$$

Expected Profitability of Processing is calculated in order to capture the short term profitability of current processing operations, i.e., the unit profit of additional one unit of fruit processed into bulk food. Expected Unit Raw Fruit Material Cost times Fruit Processing Yield is the unit raw material cost and Expected Variable Cost of Processing represents the unit operational cost. Financial Aid for Fruit Processing is also a component of the profitability which supports the unit benefit of processing. Since a stakeholder cannot operate under minimum price, Expected Profitability of Processing is bounded below with 0.

$$\textbf{Reference Profitability of Processing} = \text{Constant.} \tag{5.155}$$

Reference Profitability of Processing represents the normal, desired level of unit profitability of the processing operations. When the profit is lower (higher) than the reference value, then its effect on packaging operations becomes larger (smaller) than 1.

5.12 Retail Price Setting Sector

Retail price emerges depending on the food packaging costs, packaged food inventory coverage and export price of packaged food. Stock and flow structure for Retail Price Setting can be seen in Figure 5.9.

Expected Retail Price (t) = Expected Retail Price (t - dt)
+ (Rate of Change in Retail Price) * dt. (5.156)

Expected Retail Price increases or decreases with Rate of Change in Expected Retail Price.

Rate of Change in Expected Retail Price = (Indicated Retail Price - Expected Retail Price) / Expected Retail Price Adjustment Time. (5.157)

Rate of Change in Expected Retail Price takes on a positive value if Indicated Retail Price is higher than Expected Retail Price, and takes on a negative value if Indicated Retail Price is lower than Expected Retail Price.

Indicated Retail Price = MAX (Minimum Retail Price, Retail Price). (5.158)

Indicated Retail Price is the maximum of Minimum Retail Price and Retail Price.

Expected Retail Price Adjustment Time = Constant. (5.159)

Expected Retail Price adjusts with a delay to the retail price indicated by the effects of packaging costs, inventory coverage and international export price. Expected Retail Price Adjustment Time indicates the average length of that delay and determines the magnitude of Rate of Change in Expected Retail Price. It is assumed to be a constant value for the time horizon of the model.

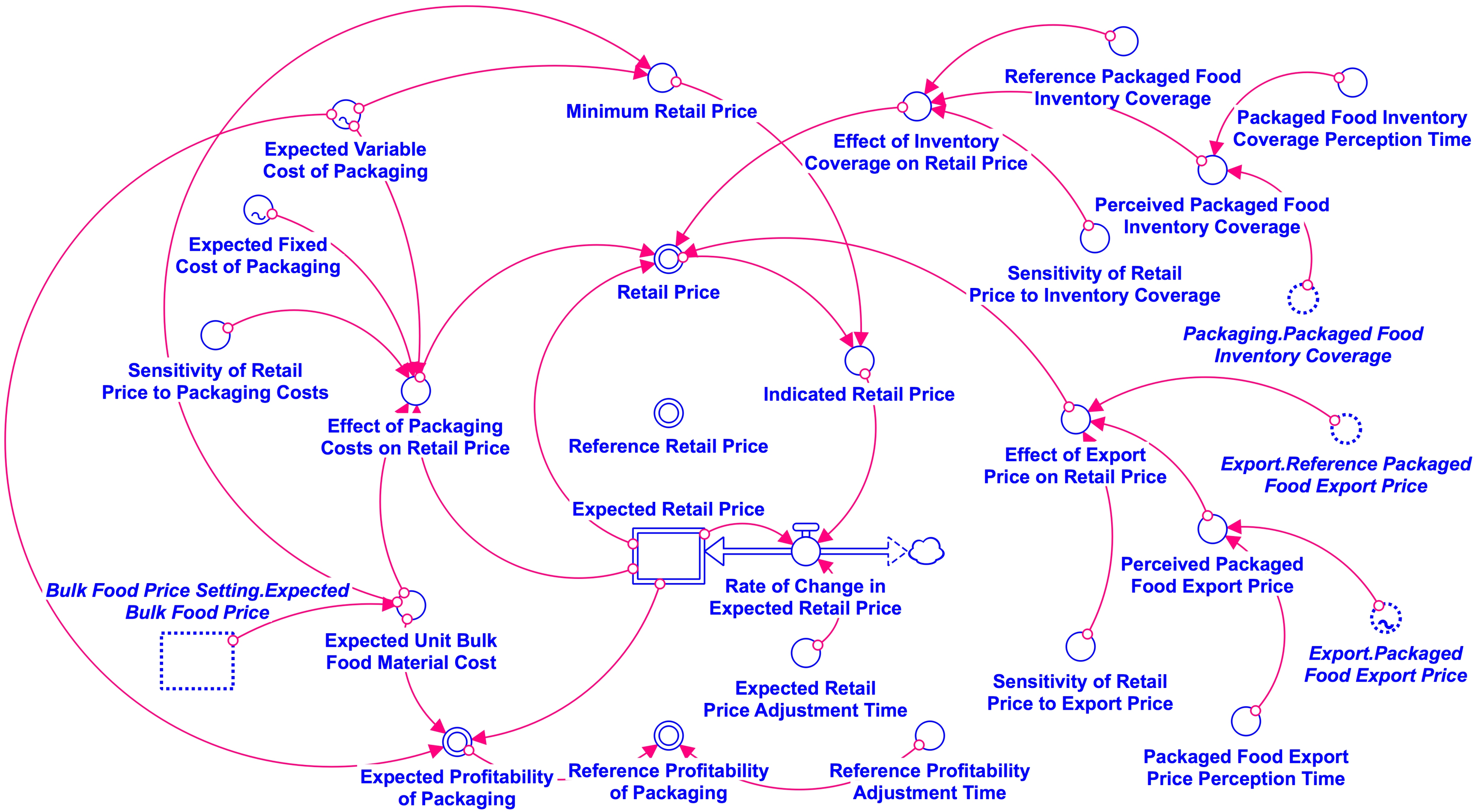

Figure 5.9: Stock and Flow Diagram of the Retail Price Setting Module

Minimum Retail Price = Expected Unit Bulk Food Material Cost + Expected Variable Cost of Packaging. (5.160)

Retail Price may temporarily fall below the total cost of farming, harvesting, processing and packaging. Yet, a producer or a packaging company can not operate if the unit retail price is lower than the total unit variable cost. In this setting, Expected Unit Bulk Food Material Cost is the unit variable material cost and Expected Variable Cost of Packaging behaves as the unit variable operational cost. Hence, lower bound of the retail price is set to the summation of Expected Unit Bulk Food Material Cost and Expected Variable Costs of Packaging.

Retail Price = Expected Retail Price * Effect of Packaging Costs on Retail Price * Effect of Inventory Coverage on Retail Price * Effect of Export Price on Retail Price. (5.161)

It is assumed that Retail Price increases with packaging costs and export price and decreases with inventory coverage.

Effect of Packaging Costs on Retail Price = MAX (0, 1 + Sensitivity of Retail Price to Packaging Costs * (((Expected Unit Bulk Food Material Cost + Expected Variable Cost of Packaging + Expected Fixed Cost of Packaging) / Expected Retail Price) - 1)). (5.162)

Effect of Production Costs on Retail Price aims to adjust the price with respect to production costs. In Generic Commodity Market Model by Sterman (2000), Effect of Costs on Price is formulated as:

Effect of Costs on Price = 1 + Sensitivity of Price to Costs * ((Expected Production Costs / Expected Price) - 1)

This formulation is built within a commodity market model where there is one price level and one level of operation costs; i.e. it is not built for a supply chain or a value chain structure. Hence, we modify the Effect of Packaging Costs on Retail Price accordingly. In order to reflect the chain structure, we added Expected Unit Bulk Food Material Cost as the variable unit material cost.

In this modified Effect of Packaging Costs on Retail Price formulation, if all relevant production costs (material cost and packaging costs: Expected Unit Bulk Food Material Cost + Expected Variable Cost of Packaging + Expected Fixed Cost of Packaging) are higher than the Expected Retail Price, then it takes on a value higher than 1; else, it takes on a value lower than 1. For the effect function not to take negative values in extreme conditions, it is bounded below with 0.

Effect of Inventory Coverage on Retail Price = (Perceived Packaged Food Inventory Coverage / Reference Packaged Food Inventory Coverage) ^ Sensitivity of Retail Price to Inventory Coverage. (5.163)

Effect of Export Price on Retail Price = (Perceived Packaged Food Export Price / Reference Packaged Food Export Price) ^ Sensitivity of Retail Price to Export Price. (5.164)

Effect of Inventory Coverage and Export Price on Retail Price are formulated as exponential effect functions as explained in Appendix A. Depending on the relative value of the corresponding variable to its reference value, effect variables take on values higher than or smaller than 1.

Sensitivity of Retail Price to Packaging Costs = Constant > 0. (5.165)

Retail Price is assumed to respond to changes in packaging costs. Sensitivity of Retail Price to Packaging Costs represents the strength of this effect. If it is equal to 0, then packaging costs do not affect the price at all. If it is equal to 1, then prices are anchored to packaging costs. In commodity markets, the response of price to costs is likely to be weak (Sensitivity of Price to Costs < 1) (Sterman, 2000). In order to determine the magnitude of the sensitivity, historical data analysis and expert opinion are utilized.

Expected Unit Bulk Food Material Cost = Expected Bulk Food Price. (5.166)

Expected Unit Bulk Food Material Cost is equal to Expected Bulk Food Price, which acts as the unit raw material cost for the packaging operations.

Expected Fixed Cost of Packaging = Graphical function. (5.167)

Expected Variable Cost of Packaging = Graphical function. (5.168)

Expected Fixed and Variable Costs of Packaging represent the unit fixed and variable costs in order to transform the bulk processed food into packaged food which is ready to sale. Since cost values are subject to change over time, graphical functions are used instead of constants or average cost values. In order to gather these graphical functions, historical data analysis and data collected from the stakeholders are utilized.

Perceived Packaged Food Inventory Coverage = SMTH1(Packaged Food Inventory Coverage, Packaged Food Inventory Coverage Perception Time).(5.169)

Perceived Packaged Food Export Price = SMTH1(Packaged Food Export Price, Packaged Food Export Price Perception Time). (5.170)

Inventory coverage levels are not perceived by the decision makers immediately, it takes time for them to realize the ratio between available supply and demand. Additionally, international export price levels require time for decision makers to perceive and benchmark. Hence, the delays in the perception of Packaged Food Inventory Coverage and Packaged Food Export Price are formulated as first-order information delay structures with exponential smoothing functions with the help of built-in SMTH function of Stella. The details of common delay structures can be seen in Appendix A.

Packaged Food Inventory Coverage Perception Time = Constant. (5.171)

Packaged Food Export Price Perception Time = Constant. (5.172)

Packaged Food Inventory Coverage Perception Time and Export Price Perception Time variables indicate the times required for decision makers to realize and adjust their perceptions on the inventory coverage level and packaged food export price level and hence adjust their price setting decisions.

Reference Packaged Food Inventory Coverage = Constant. (5.173)

Reference Packaged Food Inventory Coverage represents the desired level of inventory coverage by the producers and packaging companies. When the inventory coverage is lower (higher) than the reference value, then its effect on retail price becomes larger (smaller) than 1.

$$\textbf{Sensitivity of Retail Price to Inventory Coverage} = \text{Constant} < 0. \quad (5.174)$$

$$\textbf{Sensitivity of Retail Price to Export Price} = \text{Constant} > 0. \quad (5.175)$$

Retail Price is assumed to respond to changes in Packaged Food Inventory Coverage and Export Price. Sensitivity of Retail Price to Inventory Coverage and Sensitivity of Retail Price to Export Price represent the strength of these effects. If a sensitivity value is equal to 0, then a change in the corresponding variable does affect the retail price at all. If a sensitivity value is equal to 1 (or -1 depending on its sign), then the retail price is perfectly adjusted with respect to relative change of the corresponding variable.

Expected Profitability of Packaging = MAX(0, Expected Retail Price - Expected Unit Bulk Food Material Cost-Expected Variable Cost of Packaging). (5.176)

Expected Profitability of Packaging is calculated in order to capture the short term profitability of current packaging operations, i.e., the unit profit of additional one unit of food packaged. Expected Unit Bulk Food Material Cost is the unit raw material cost and Expected Variable Cost of packaging represents the unit operational cost. Since a stakeholder cannot operate under minimum price, Expected Profitability of Packaging is bounded below with 0.

Reference Profitability of Packaging = SMTH1 (Expected Profitability of Packaging, Reference Profitability of Packaging Adjustment Time). (5.177)

Reference Profitability of Packaging represents the normal, desired level of unit profitability by the producers and packaging companies. When the profit is lower (higher) than the reference value, then its effect on packaging operations becomes larger (smaller) than 1. Reference Profitability of Packaging is updated with realizations on expected profitability of packaging operations. It is formulated with the typical first-order information delay structure. The details of common delay structures can be seen in Appendix A.

$$\textbf{Reference Profitability of Packaging Adjustment Time} = \text{Constant}. \quad (5.178)$$

Reference Profitability of Packaging Adjustment Time indicates the average time value required for decision makers to realize and adjust their perception on the reference profitability of packaging and hence change their packaging rate decisions.

In this chapter, we provide the details of Agricultural Commodity Value Chain model with its structure and behavior: definitions, assumptions, principles, modules, stocks-and-flow diagrams, variables and all analytical and mathematical relationships. Before implementing the model to the olive oil case in Turkey, we make initial set of synthetic parameters assignments, make complete model runs, perform relevant structural tests and conduct an initial policy analysis for a hypothetical case of a country in Chapter 6.

CHAPTER 6

A NUMERICAL STUDY: POLICY ANALYSIS FOR THE MITIGATION OF PRICE FLUCTUATIONS

6.1 Introduction

In this chapter, we provide the results of the numerical study conducted with our generic agricultural value chain model. With a stylized parameter setting, we first present Base Case results, which show the reference mode behavior along the agricultural value chain. Then, we propose some modifications for the selected variables to represent the settings of a special case, such as population growth, increase in income, increase in export volume, etc. In this setting, we observe price fluctuations and widening gaps along the agricultural value chain price levels. In the policy analysis step, we analyze the performance of two sets of value chain interventions, namely, technology investments and financial aid improvements, in mitigating these price fluctuations.

The aim of this chapter is to show the importance of utilizing dynamic models in understanding agricultural value chain dynamics by means of a numerical example: our quantitative policy analysis results show that similar amount of investments or improvements in different stages of the agricultural value chain leads to significantly different results. Some improvement policies, unexpectedly, may even trigger other more severe price shocks due to endogenous structures within the chain. Throughout the chapter, we present the details of model settings and policy analysis results in detail.

Before presenting the results, it should be stated that relevant validity tests have been completed for the model. On the validation of system dynamics models, the most fundamental studies in the field, such as Barlas and Carpenter (1990) and Barlas (1994), put emphasis on the fact that model validation is about establishing confidence in the usefulness of a model with respect to its purpose. The purpose of our model is to build a theory for the dynamic relationships in agricultural value chains and to demonstrate the fact that, even for a stylized and synthetic parameter set which includes several constants and simplified linear functions on their own, the effects of changes in policy parameters are somehow counter-intuitive. Rather than predicting the real-world agricultural value chain dynamics of a particular commodity of a particular country, the purpose of our model is more being explanatory and exploratory. Hence, structural validity tests are sufficient for our model purpose.

In selecting and implementing the corresponding structural validity tests, the concrete guidelines presented in Barlas (1996) and Sterman (2000) are generally followed. Additionally, more recent studies on model validity test applications such as Qudrat-Ullah (2005), and Qudrat-Ullah and Seong (2010) are utilized.

The tests conducted at this stage can be summarized as follows:

- Direct Structure Tests: Direct Structure Tests focus on evaluating the model structure. At that stage, no simulation run is involved. All relationships in the model are treated individually and compared with available knowledge in the real system or in the literature.
  - Structural Confirmation Tests: Structural confirmation tests aim to confirm the form of the equations in the model by comparing them with the available knowledge about the system. They are highly qualitative type of tests by their nature. The main sources that are used for structural confirmation are the relevant system dynamics and economics literature, information about the agricultural value chains gathered from reports published by institutions and historical dynamic data analysis as well.
  - Parameter Confirmation Tests: In parameter confirmation tests, it is inquired whether each parameter in the model has a real world counterpart. Additionally, the consistency of parameter values with relevant descriptive knowledge of the real world system is controlled.
  - Direct Extreme Condition Tests: In Direct Extreme Condition tests, we

check whether each single equation makes sense even when its inputs take on extreme values. Without any simulation runs, we take each equation individually, take its inputs to extreme values, anticipate on the output results, and compare the value of the output with our anticipation, make proper modifications where needed, and then repeat the tests.

  – Dimensional Consistency Tests: In Dimensional Consistency tests, we check whether each equation in the model is dimensionally consistent without the use of parameters having no real world meaning.

- Structure-Oriented Behavior Tests: Structure-Oriented Behavior Tests focus on evaluating the model structure indirectly, by considering the model-generated behavior patterns. At this stage, simulation is involved including either the whole model or only some modules.

  – Extreme Condition Tests: In Extreme conditions test, we run the complete simulation model after setting selected parameters to extreme values, and comparing model results with our anticipations on the model behavior. In Direct Extreme Condition tests, we consider one equation at a time and no simulation run is involved. However, in Extreme Condition tests, we run the whole simulation model and check if the model results are consistent with our anticipated model behavior.

  – Behavior Sensitivity Tests: Behavior sensitivity tests focus on determining the parameters to which the model results are sensitive and questioning whether these sensitivities would exist in the real world. Behavior sensitivity tests require a parameter set to be assigned and provide implications for the possible results of numerical policy and scenario analysis. Hence, before conducting policy analysis, behavior sensitivity tests are conducted with the initial parameter set. The results and implications of behavior sensitivity test for the base case are presented in detail in Section 6.3.

In all runs, time unit is one month, while time horizon is 180 months (15 years) and delta time step (*dt*) is 1/8 months. The value of *dt*, which is selected according to the guideline for numerical integration provided by Sterman (2000), is set to one-fourth of the smallest time constant in our model. Additionally, integration error tests are conducted to see whether the model results are robust to the choice of time step. As the integration method of the model, Euler is used. We first provide the base case results and then policy analysis results for the special case.

6.2 Base Case: Reference Mode

In the base case, almost every exogenous variable is assumed to be constant. The parameter settings of the Base Case for the exogenous variables can be found in Tables 6.1 - 6.9. The only non-constant exogenous variable is Alternation in Harvesting module. It represents the "up year - down year" behavior of the fruits on the trees. In order to capture the effect of this variable, both "Base Case with Alternation" and "Base Case without Alternation" cases are graphically presented in the following parts.

As for the endogenous variables in the base case, most of them show an oscillating behavior, as expected. Tree levels, inventory levels, prices and other corresponding endogenous variables oscillate depending on their equations. To illustrate the behavior in the base case, see the behavior of price levels along the value chain in Figures 6.1 and 6.2: fruit price, bulk food price and retail price. The axis on the left belongs to bulk food price and retail price, whereas the axis on the right belongs to fruit price. The oscillating behavior in prices stem from the stock-and-flow structures within the model and delayed adjustment of supply, demand and prices. The effect of Alternation can be graphically observed when Figures 6.1 and 6.2 are compared: in Figure 6.1, the height of oscillations is different from one harvest season to another due to "up year - down year" behavior. On the other hand, when there is no Alternation effect as in Figure 6.2, the oscillatory waves are almost identical over the years after the warm-up period.

Table 6.1: Planting Module Parameter Settings in the Base Case

Mature Trees (t_0) = 109,160 K (Units)

Young Trees (t_0) = 10,916 K (Units)

Desired Tree Stock Adjustment Time = 12 (Months)

Financial Supports for Planting = 10 (Euros/Unit)

Life Time = 600 (Months)

Maturation Time = 60 (Months)

Minimum of Effect of Financial Supports = 0.15 (Dimensionless)

Planting Adjustment Time = 12 (Months)

Planting Costs = 40 (Euros Unit)

Planting Period = IF ((TIME MOD 12) $>=$ 0 AND (TIME MOD 12) $<$ 6) THEN 1 ELSE 0 (Dimensionless)

Reference Financial Supports for Planting = 10 (Euros/Unit)

Reference Planting Costs = 40 (Euros/Unit)

Reference Tree Stock Level = 109,160 K (Units)

Sensitivity of Tree Stocks to Financial Supports = 0.7 (Dimensionless)

Sensitivity of Tree Stocks to Fruit Price = 0.25 (Dimensionless)

Sensitivity of Tree Stocks to Planting Costs = -0.7 (Dimensionless)

Table 6.2: Harvesting Module Parameter Settings in the Base Case

Harvest Amount (t_0) = 0 (Kilograms)

Perceived Harvest Amount (t_0) = 840,000 K (Kilograms)

Alternation in Base Case = IF ((TIME MOD 24) >= 0 AND (TIME MOD 24) < 12) THEN 1 ELSE 0 (Dimensionless)

Alternation in Base Case without Alternation = 1 (Dimensionless)

Fruits per Tree = Alternation * 9 + (1 - Alternation) * 8 (Kilograms/Unit)

Harvest Perception Time = 1 (Months)

Harvest Time = 3 (Months)

Reference Harvest Amount Adjustment Time = 3 (Months)

Reference Harvest Utilization = 0.95 (Dimensionless)

Sensitivity of Harvest Rate to Profitability = 0.15 (Dimensionless)

Share of Bearing Trees = 0.9 (Dimensionless)

Share of Fruits for Processing = 0.7 (Dimensionless)

Table 6.3: Processing Module Parameter Settings in the Base Case

Processed Bulk Food Inventory (t_0) = 9,800 K (Kilograms)

Bulk Food Export Time = 1 (Months)

Processing Yield = 0.2 (Dimensionless)

Reference Process Utilization = 1 (Dimensionless)

Sensitivity of Process Utilization to Profitability = 0.20 (Dimensionless)

Table 6.4: Packaging Module Parameter Settings in the Base Case

Packaged Food Inventory (t_0) = 8,000 K (Kilograms)
Desired Packaging Rate Adjustment Time = 1 (Months)
Distribution and Retailing Time = 0.5 (Months)
Maximum Utilization = 1 (Dimensionless)
Packaged Food Export Time = 1 (Months)
Packaging Time = 0.5 (Months)
Sensitivity of Packaging Rate to Profitability = 0.25 (Dimensionless)
Total Packaging Period = 12 (Months)

Table 6.5: Demand Module Parameter Settings in the Base Case

Demand (t_0) = 7,000 K (Kilograms / Months)
Demand Adjustment Time = 1 (Months)
GDP per Capita = 1,450 (Euros/Person)
Market Trend = 30 (Dimensionless)
Maximum Consumption = 20,000 K (Kilograms/Month)
Population = 70,000 K (People)
Reference Demand per Capita = 0.1 (Kilograms/Month)
Reference GDP per Capita = 1,450 (Euros/Person)
Reference Market Trend = 30 (Dimensionless)
Reference Substitute Price = 2.75 (Euros/Kilogram)
Sensitivity of Demand to Consumer Price = -0.7 (Dimensionless)
Sensitivity of Demand to GDP per Capita = 0.3 (Dimensionless)
Sensitivity of Demand to Market Trend = 0.3 (Dimensionless)
Sensitivity of Demand to Substitute Price = 0.3 (Dimensionless)
Substitute Price = 2.75 (Euros/Kilogram)

Table 6.6: Export Module Parameter Settings in the Base Case

Bulk Food Export Price = 3 (Euros/Kilogram)
Packaged Food Export Price = 4 (Euros/Kilogram)
Rate of Bulk Food Export Quantity Demanded = 1,800 K (Kilograms/Month)
Rate of Packaged Food Export Quantity Demanded = 1,000 K (Kilograms/ Month)
Reference Bulk Export Price Adjustment Time = 12 (Months)
Reference Packaged Export Price Adjustment Time = 12 (Months)

Table 6.7: Fruit Price Setting Module Parameter Settings in the Base Case

Expected Fruit Price (t_0) = 0.9 (Euros/Kilogram)
Expected Fixed Cost of Harvesting = 0.3 (Euros/Kilogram)
Expected Fruit Price Adjustment Time = 1 (Months)
Expected Variable Cost of Harvesting = 0.8 (Euros/Kilogram)
Financial Aid for Harvesting = 0.2 (Euros/Kilogram)
Reference Fruit Price = 0.9 (Euros/Kilogram)
Reference Profitability of Harvesting Adjustment Time = 12 (Months)
Sensitivity of Fruit Price to Bulk Food Price = 0.5 (Dimensionless)
Sensitivity of Fruit Price to Harvest Amount = -0.35 (Dimensionless)
Sensitivity of Fruit Price to Harvesting Costs = 0.7 (Dimensionless)

Table 6.8: Bulk Food Price Setting Module Parameter Settings in the Base Case

Expected Bulk Food Price (t_0) = 4.5 (Euros/Kilogram)
Bulk Food Export Price Perception Time = 3 (Months)
Bulk Food Inventory Coverage Perception Time = 1 (Months)
Expected Bulk Food Price Adjustment Time = 1 (Months)
Expected Fixed Cost of Processing = 0.5 (Euros/Kilogram)
Expected Variable Cost of Processing = 0.3 (Euros/Kilogram)
Financial Aid for Fruit Processing = 0.8 (Euros/Kilogram)
Reference Bulk Food Price Adjustment Time = 12 (Months)
Reference Profitability of Processing = 0.5 (Euros/Kilogram)
Reference Retail Price Adjustment Time = 12 (Months)
Sensitivity of Bulk Food Price to Export Price = 0.3 (Dimensionless)
Sensitivity of Bulk Food Price to Inventory Coverage = -0.35 (Dimensionless)
Sensitivity of Bulk Food Price to Retail Price = 0.5 (Dimensionless)
Sensitivity of Bulk Price to Processing Costs = 0.7 (Dimensionless)

Table 6.9: Retail Price Setting Module Parameter Settings in the Base Case

Expected Retail Price (t_0) = 7 (Euros/Kilogram)
Expected Fixed Cost of Packaging = 1 (Euros/Kilogram)
Expected Retail Price Adjustment Time = 1 (Months)
Expected Variable Cost of Packaging = 1.5 (Euros/Kilogram)
Packaged Food Export Price Perception Time = 3 (Months)
Packaged Food Inventory Coverage Perception Time = 1 (Months)
Reference Packaged Food Inventory Coverage = 1 (Months)
Reference Profitability Adjustment Time = 12 (Months)
Reference Retail Price = 7 (Euros/Kilogram)
Sensitivity of Retail Price to Export Price = 0.3 (Dimensionless)
Sensitivity of Retail Price to Inventory Coverage = -0.35 (Dimensionless)
Sensitivity of Retail Price to Packaging Costs = 0.7 (Dimensionless)

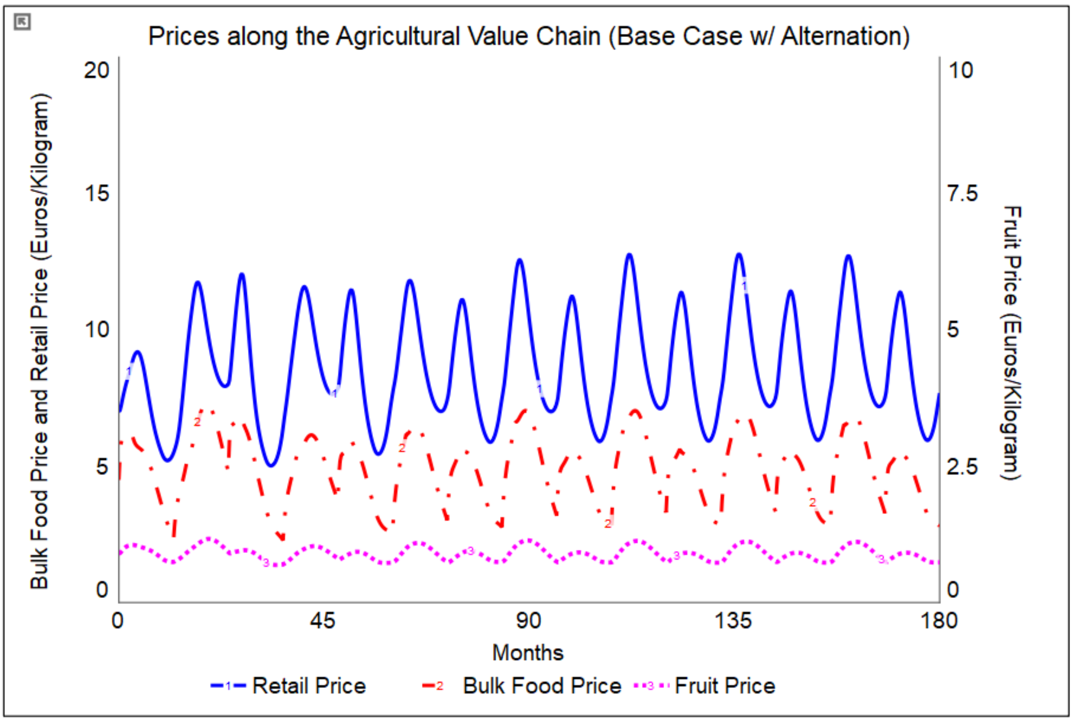

Figure 6.1: Prices along the Agricultural Value Chain in the Base Case with Alternation

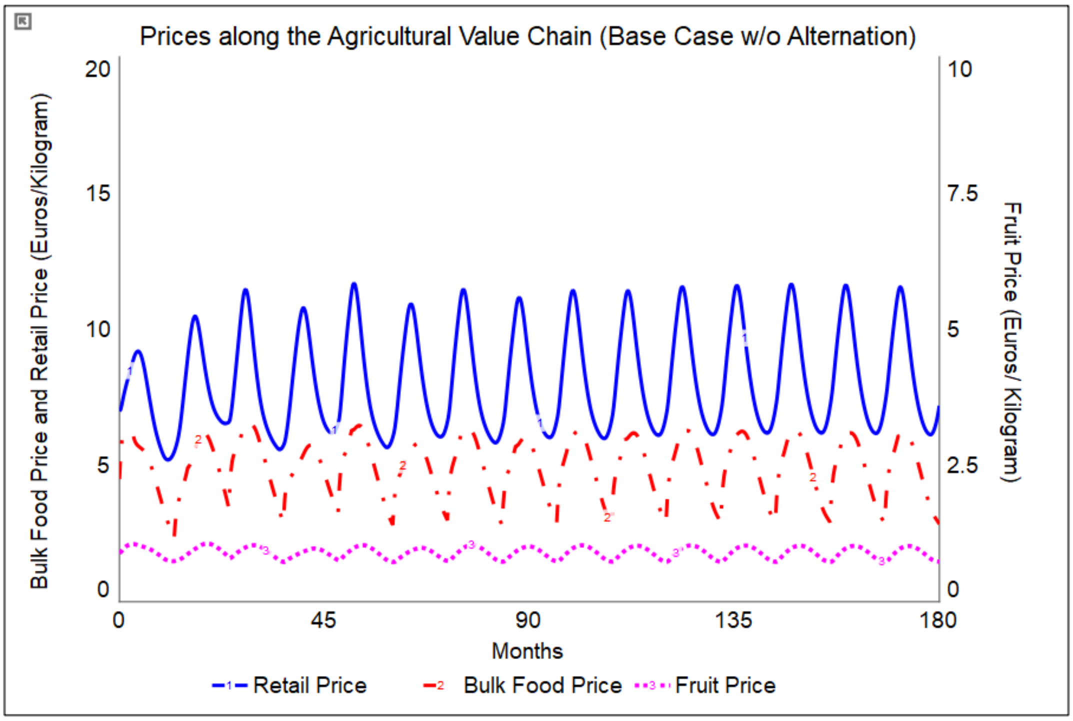

Figure 6.2: Prices along the Agricultural Value Chain in the Base Case without Alternation

6.3 Behavior Sensitivity Test for the Base Case

As it is mentioned previously, behavior sensitivity tests focus on determining the parameters to which the model results are sensitive and questioning whether these sensitivities would be observed in the real world. For this purpose, behavior sensitivity tests are conducted for each exogenous parameter in the Base Case. These parameters are altered within their own -20% - +20% range and the resulting fruit price, bulk food price and retail price behaviors are recorded. The parameters which result in MAPE larger than 10% are classified as “model is sensitive to”. These parameters, their test ranges and resulting MAPE values for Fruit Price, Bulk Food Price and Retail Price are presented in Tables 6.10, 6.11 and 6.12, respectively.

As the result of the behavior sensitivity tests, it can be concluded that our model is:

- robust to changing levels of “sensitivity” parameters in the effect functions,
- sensitive to costs and financial aids especially in Planting and Harvesting modules,
- sensitive to parameters which are “direct multipliers” of demand and supply volume, i.e. Population, Fruits per Mature Tree, Processing Yield, etc.,
- sensitive to some “Reference” values, which is expected since these reference values are the main determinants of the regarding effect functions.

The results of behavior sensitivity tests are consistent with our anticipations on the model behavior and hence the model is accepted to pass the tests. These results constitute a guideline for the proceeding steps in building the special case for numerical analysis and assessing the policy analysis results.

Table 6.10: Behavior Sensitivity Test Results in the Base Case - MAPE in Fruit Prices (FP)

Module	**Variable**	**Min.**	**Max.**	**FP MAPE (Min.)**	**FP MAPE (Max.)**
Demand	Population	56,000	84,000	11.6%	5.1%
Demand	Reference Demand per Capita	0.08	0.12	11.6%	5.1%
Fruit Price	Expected Fixed Cost of Harvesting	0.24	0.36	10.7%	7.0%
Fruit Price	Expected Variable Cost of Harvesting	0.64	0.96	18.5%	22.3%
Harvesting	Share of Fruits for Processing	0.56	0.84	8.2%	15.5%
Planting	Reference Tree Stock Level	87,328	130,992	6.1%	17.8%
Processing	Reference Process Utilization	0.8	1	13.6%	0%

Table 6.11: Behavior Sensitivity Test Results in the Base Case - MAPE in Bulk Food Prices (BP)

Module	**Variable**	**Min.**	**Max.**	**BP MAPE (Min.)**	**BP MAPE (Max.)**
Demand	Population	56,000	84,000	22.6%	10.1%
Demand	Reference Demand per Capita	0.08	0.12	22.6%	10.1%
Fruit Price	Expected Fixed Cost of Harvesting	0.24	0.36	9.1%	15.9%
Fruit Price	Expected Variable Cost of Harvesting	0.64	0.96	19.8%	25.9%
Fruit Price	Financial Aid for Harvesting	0.16	0.24	13.1%	7.1%
Harvesting	Reference Harvest Utilization	0.76	1	16.3%	4.8%
Harvesting	Share of Bearing Trees	0.72	1	16.1%	13.0%
Harvesting	Share of Fruits for Processing	0.56	0.84	16.5%	32.1%
Planting	Financial Supports for Planting	8	12	12.2%	15.5%
Planting	Mature Trees (t_0)	87,328	130,992	5.6%	10.4%
Planting	Planting Costs	32	48	18.9%	11.7%
Planting	Reference Financial Supports for Planting	8	12	18.9%	11.7%
Planting	Reference Planting Costs	32	48	12.2%	15.5%
Planting	Reference Tree Stock Level	87,328	130,992	11.7%	39.2%
Processing	Processing Yield	0.16	0.24	38.3%	21.3%

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Table 6.11 – *Continued from previous page*

Module	**Variable**	**Min.**	**Max.**	**BP MAPE (Min.)**	**BP MAPE (Max.)**
Processing	Reference Process Utilization	0.8	1	27.4%	0%
Retail Price	Expected Retail Price (t_0)	5.6	8.4	21.8%	6.6%
Retail Price	Reference Retail Price	5.6	8.4	12.7%	7.8%

Table 6.12: Behavior Sensitivity Test Results in the Base Case - MAPE in Retail Prices (RP)

Module	**Variable**	**Min.**	**Max.**	**RP MAPE (Min.)**	**RP MAPE (Max.)**
Demand	Population	56,000	84,000	19.4%	14.9%
Demand	Reference Demand per Capita	0.08	0.12	19.4%	14.9%
Fruit Price	Expected Fixed Cost of Harvesting	0.24	0.36	4.9%	12.9%
Fruit Price	Expected Variable Cost of Harvesting	0.64	0.96	10.8%	11.5%
Fruit Price	Reference Fruit Price	0.72	1.08	10.6%	8.1%
Harvesting	Reference Harvest Utilization	0.76	1	27.1%	6.6%
Harvesting	Share of Bearing Trees	0.72	1	27.4%	15.3%
Harvesting	Share of Fruits for Processing	0.56	0.84	29.8%	27.1%
Planting	Financial Supports for Planting	8	12	19.4%	17.6%
Planting	Planting Costs	32	48	19.5%	17.6%
Planting	Reference Financial Supports for Planting	8	12	19.5%	17.6%
Planting	Reference Planting Costs	32	48	19.4%	17.6%
Planting	Reference Tree Stock Level	87,328	130,992	21.4%	29.7%
Processing	Processing Yield	0.16	0.24	38.7%	25.4%
Processing	Reference Process Utilization	0.8	1	20.6%	0%

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Table 6.12 – *Continued from previous page*

Module	**Variable**	**Min.**	**Max.**	**RP MAPE (Min.)**	**RP MAPE (Max.)**
Retail Price	Expected Retail Price (t_0)	5.6	8.4	19.8%	6.4%
Retail Price	Reference Retail Price	5.6	8.4	15.2%	11.0%
Retail Price	Sensitivity of Retail Price to Inventory Coverage	-0.28	-0.42	8.1%	10.5%

6.4 Special Case: Fluctuating Prices

In this section, we make some modifications in selected parameters and illustrate a special case which results in fluctuations in prices along the agricultural value chain. The modifications in this special case are inspired by the behavioral sensitivity test results and the recent advances experienced in the olive oil value chain in Turkey.

The behavior sensitivity tests reveal that the model results are sensitive to parameters which are "direct multipliers" of demand and supply volume. In that sense, one parameter for modification in the special case is selected as "Population": instead of a constant value, population is defined as having an increasing trend. In addition to population, since our case is inspired by Turkey which is a developing country, income per capita is also defined as having an increasing trend.

We remind that the agricultural commodity value chain model given in Chapter 5 is valid for a country which is not a "big player" in the global trade and a price taker rather than a price maker in the world market. Hence, for the special case, the parameters regarding export quantity and export price are modified. Due to increasing world demand for food and agricultural products, export quantity demanded is defined as increasing. On the other hand, export prices are defined as including "shocks" rather than "trends". These price shocks are inevitable for the countries which are not price makers but price takers in the world market. For instance, starting from early 2013 to late 2015, unit export price of olive oil for Turkey has increased by almost 80% in US Dollars and then in less than one year, it has dropped by 40% (Data Source: TÜİK Database.) This type of shocks is an exogenous effect but triggers endogenous structures along the value chain and leads to long term consequences.

To sum up, for the special case, the following parameters are selected to be modified:

- **Population**: From month 0 to month 180, Population linearly increases from 70,000 K people to 80,000 K people.
- **GDP:** From month 0 to month 180, GDP per capita (per year) linearly increases from 1450 Euros to 1750 Euros.
- **Export Quantity**: From month 0 to month 180, Bulk Food Export Quantity

(per month) linearly increases from 1800 K kilograms to 3600 K kilograms and Packaged Food Export Quantity (per month) linearly increases from 1000 K kilograms to 2000 K kilograms

- **Export Price:** Bulk Food Export Price (per kilogram) is 3 Euros in months 0 and 180, but faces a price shock between months 84 and 96 when it increases to 6 Euros. Similarly, Packaged Food Export Price (per kilogram) is 4 Euros in months 0 and 180, but faces a price shock between months 84 and 96 when it increases to 8 Euros.

The modifications made for the special case can be found in Table 6.13 in numerical form and in Figures 6.3-6.8 in graphical form.

Table 6.13: Modified Parameter Settings in the Special Case

GDP per Capita = GRAPH (TIME, VALUE) (0.0, 1450), (180.0, 1750)
Population = GRAPH (TIME, VALUE) (0.0, 70000), (180.0, 80000)
Bulk Food Export Price = GRAPH (TIME, VALUE) (0.0, 3.00), (12.0, 3.00), (24.0, 3.00), (36.0, 3.00), (48.0, 3.00), (60.0, 3.00), (72.0, 3.00), (84.0, 6.00), (96.0, 6.00), (108.0, 3.00), (120.0, 3.00), (132.0, 3.00), (144.0, 3.00), (156.0, 3.00), (168.0, 3.00), (180.0, 3.00)
Packaged Food Export Price = GRAPH (TIME, VALUE) (0.0, 4.00), (12.0, 4.00), (24.0, 4.00), (36.0, 4.00), (48.0, 4.00), (60.0, 4.00), (72.0, 4.00), (84.0, 8.00), (96.0, 8.00), (108.0, 4.00), (120.0, 4.00), (132.0, 4.00), (144.0, 4.00), (156.0, 4.00), (168.0, 4.00), (180.0, 4.00)
Rate of Bulk Food Export Quantity Demanded = GRAPH (TIME, VALUE) (0.0, 1800), (180.0, 3600)
Rate of Packaged Food Export Quantity Demanded = GRAPH (TIME, VALUE) (0.0, 1000), (180.0, 2000)

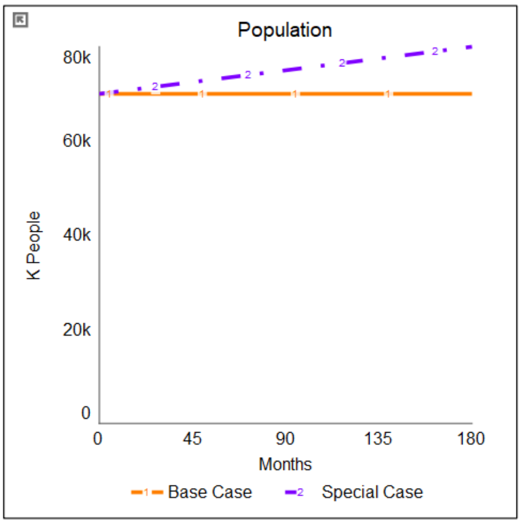

Figure 6.3: Population in the Base and Special Cases

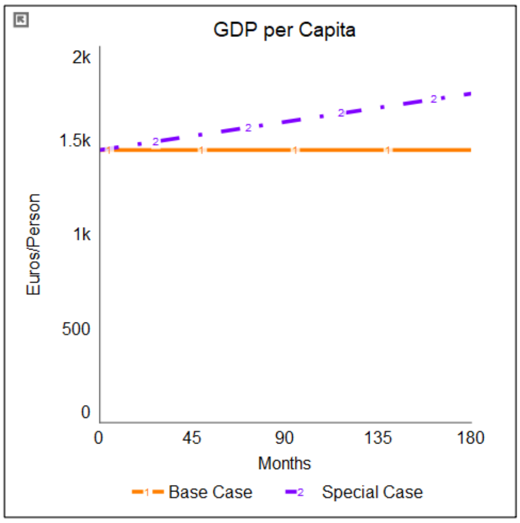

Figure 6.4: GDP in the Base and Special Cases

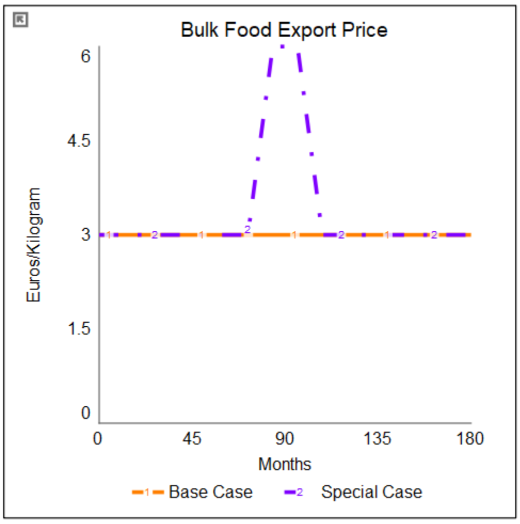

Figure 6.5: Bulk Food Export Price in the Base and Special Cases

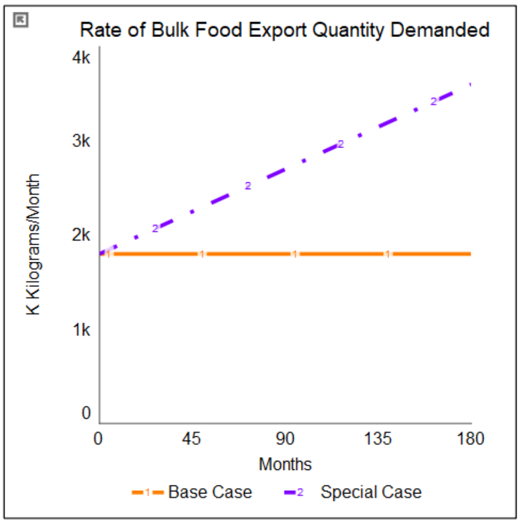

Figure 6.6: Bulk Food Export Quantity in the Base and Special Cases

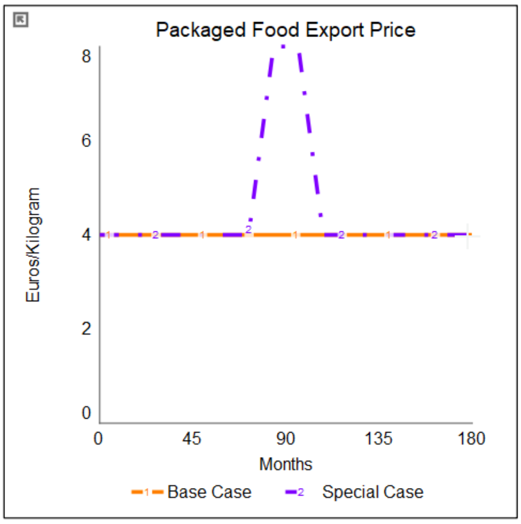

Figure 6.7: Packaged Food Export Price in the Base and Special Cases

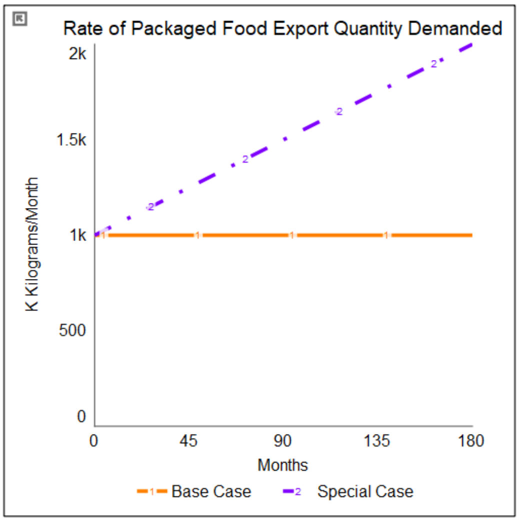

Figure 6.8: Packaged Food Export Quantity in the Base and Special Cases

Similar to representations in the Base Case, "Special Case with Alternation" and "Special Case without Alternation" settings are both graphically presented in Figures 6.9 and 6.10. The effect of Alternation can be graphically observed when Figures 6.9 and 6.10 are compared: in Figure 6.9, the prices exhibit sharper fluctuations with the additional effect of "up year - down year" behavior. On the other hand, when there is no Alternation effect as in Figure 6.10, the prices exhibit rather smoother oscillations with a significant trend. After around month 100, their behavior become quite similar.

When we compare the base case results with the special case results, similar patterns of prices are observed along the value chain at the beginning, while an increasing trend is observed later in retail prices in the special case. In around month 90, the retail price reaches a very high level. After a short period of stabilization for all prices between months 100 and 120, sharp price fluctuations are experienced later for several times, even though the exogenous "shock" effect of export prices was already diminished. Additionally, the gap among the different price levels widens from month 90 towards month 180.

In the special case, the dynamics behind increases in prices can be summarized as follows: with increasing export quantities, the available olive oil in the domestic market decreases in the meantime. As a results, national inventory level of Packaged Food

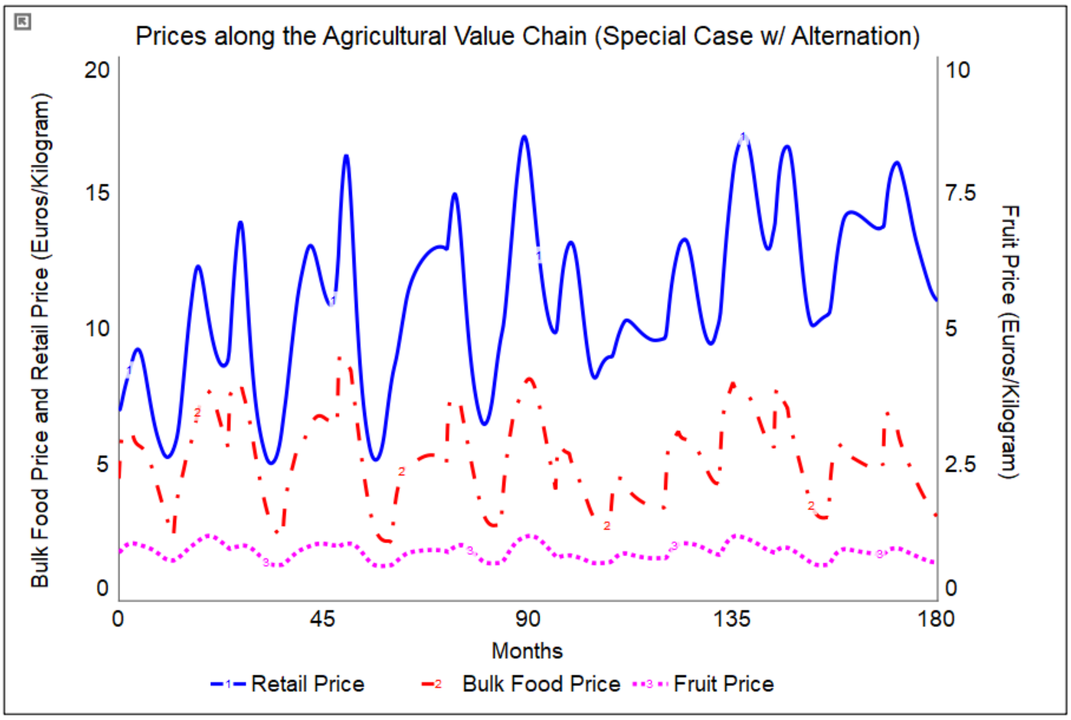

Figure 6.9: Prices along the Agricultural Value Chain in the Special Case with Alternation

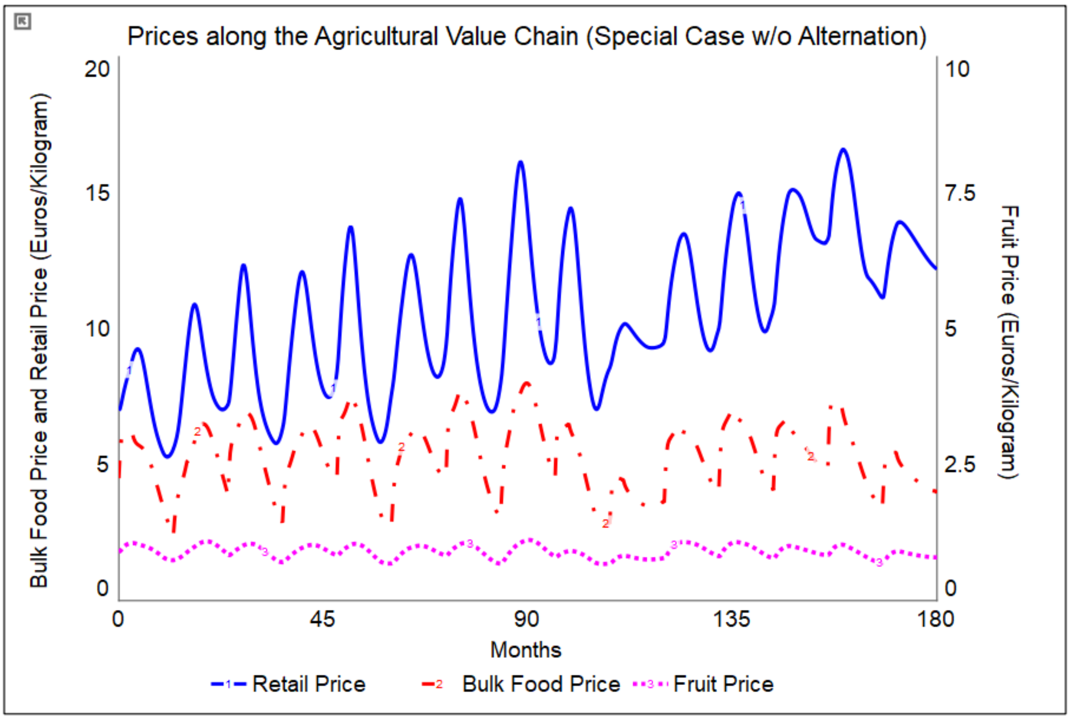

Figure 6.10: Prices along the Agricultural Value Chain in the Special Case without Alternation

Inventory and Inventory Coverage decrease. Additionally, increase in Export Prices creates a higher benchmark for domestic prices. The increase in GDP and Population speeds up the decrease of Packaged Food Inventory Coverage. All of these result in an increase in Retail Prices first and then in other prices as well.

In case of sharp fluctuations in domestic market prices along the value chain, we investigate two sets of policy alternatives: technology investments and improvements in financial aids. Since sharper increases are observed in Figure 6.9 than in Figure 6.10, in the rest of the chapter, the policy analysis is conducted for the special case with alternation rather than the case without alternation.

6.5 Policy Analysis for the Special Case

The assumptions in our policy analysis for our stylized agricultural value chain model are as follows:

- Technology investments can be implemented for improvement in three areas: 1) Share of Bearing Trees, 2) Fruits per Tree and 3) Processing Yield.
- Financial support improvements can also be implemented in three areas: 1) Financial Aids for Planting, 2) Financial Aid for Harvesting, 3) Financial Aids for Processing.
- Regarding policy is adapted just before month 90, just after the observation of the highest retail price level shown in Figure 6.9.
- Budget for the policy implementation is approximately 25 M Euros per year for the time horizon of the model.
- For each technology improvement policy alternative, investment cost is reflected to the fixed cost of the regarding operation. Technology improvement elasticity of investment cost is 1, i.e. $x\%$ improvement in a selected policy area leads to $x\%$ increase in fixed cost of the regarding operation.
- Improvement in Share of Bearing Trees focuses on decreasing the ratio of non-bearing trees, i.e., when share of bearing trees is 90% and hence share of non-

bearing trees is 10%, a 50% improvement means a decreasing share of non-bearing trees with 50% which makes share of non-bearing trees 5% and hence share of bearing trees 95%.

- Improvement percentage and its regarding costs are determined/calculated depending on the average of past data between months 0 and 90, implemented just before month 90 and they are assumed to be constant until month 180, i.e. the end of the time horizon.

6.5.1 Technology Investments in the Special Case

Depending on the assumptions stated above and observing the past data between months 0 and 90, the budget for technology investment of 25 M Euros per year between months 90 and 180 corresponds to the policy parameters, i.e. improvements and increases in fixed costs, in Table 6.14. Modifications in the model parameters can be seen in Table 6.15.

Table 6.14: Technology Investment Policies in the Special Case

Policy Area	Improvement	Investment Cost
1 - Share of Bearing Trees	10%	10% increase in Fixed Cost of Harvesting
2 - Fruits per Tree	10%	10% increase in Fixed Cost of Harvesting
3 - Processing Yield	35%	35% increase in Fixed Cost of Processing

The resulting retail prices of the three technology investment policy runs compared to the the base case and the special case can be found in Figure 6.11.

At first glance in Figure 6.11, the striking observation is that investments in the share of bearing trees and fruits on trees could not be as effective as the investments in processing yield in terms of stabilizing the retail prices. Increasing fruits per tree somehow begins to mitigate the price fluctuations between months 130 and 150, but gives rise to another bigger price shock around month 170. The reason of this price shock can be summarized as follows: low level of Bulk Food Prices between months

Table 6.15: Modified Parameter Settings under Technology Investment Policies

1 - Share of Bearing Trees (10%)

Share of Bearing Trees = GRAPH (TIME, VALUE) (0.0, 0.900), (90.0, 0.910), (180.0, 0.910)

Expected Fixed Cost of Harvesting = GRAPH (TIME, VALUE) (0.0, 0.300), (90.0, 0.330), (180.0, 0.330)

2 - Fruits per Tree (10%)

Fruits per Tree = IF TIME >= 90 THEN Alternation * 9.9 + (1 - Alternation) * 8.8 ELSE Alternation * 9 + (1 - Alternation) * 8

Expected Fixed Cost of Harvesting = GRAPH (TIME, VALUE) (0.0, 0.300), (90.0, 0.330), (180.0, 0.330)

3 - Processing Yield (35%)

Processing Yield = GRAPH (TIME, VALUE) (0.0, 0.200), (90.0, 0.270), (180.0, 0.270)

Expected Fixed Cost of Processing = GRAPH (TIME, VALUE) (0.0, 0.500), (90.0, 0.675), (180.0, 0.675)

4 - Share of Bearing Trees (35%)

Share of Bearing Trees = GRAPH (TIME, VALUE) (0.0, 0.900), (90.0, 0.935), (180.0, 0.935)

Expected Fixed Cost of Harvesting = GRAPH (TIME, VALUE) (0.0, 0.300), (90.0, 0.405), (180.0, 0.405)

5 - Fruits per Tree (35%)

Fruits per Tree = IF TIME >= 90 THEN Alternation * 12.15 + (1 - Alternation) * 10.8 ELSE Alternation * 9 + (1 - Alternation) * 8

Expected Fixed Cost of Harvesting = GRAPH (TIME, VALUE) (0.0, 0.300), (90.0, 0.405), (180.0, 0.405)

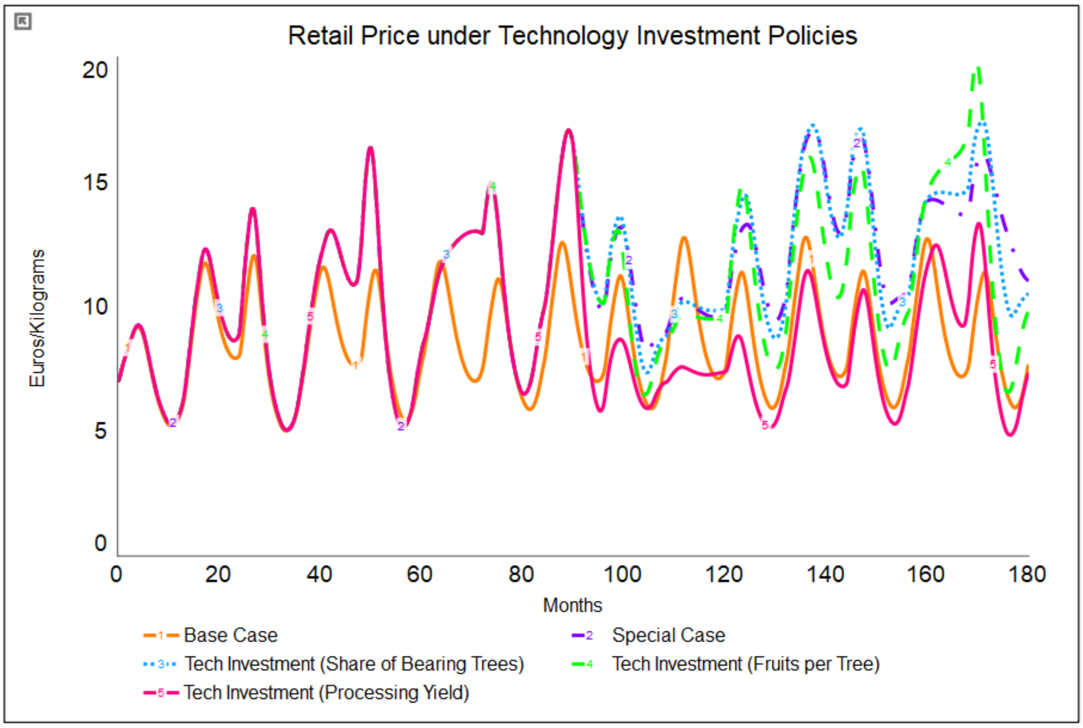

Figure 6.11: Retail Price for (1) Base Case, (2) Special Case without Policy Implementation and (3, 4, 5) Special Case under Various Technology Investment Policies

100 and 120 leads to decreases in inventory coverages. Due to low levels of inventory coverages, all three price levels fall in their positive feedback loops and they all reach to very high values around month 170. After that time, Effect of Costs and Effect of Inventory Coverages regulate prices to settle down to lower values.

Another observation in Figure 6.11 is that, increasing share of bearing trees has almost no effect in mitigating price fluctuations. However, investment in processing yield mitigates the price shocks in a much shorter time and retail price starts to behave closer to the base run. The reason is that, with increasing processing yield, expected raw material cost of bulk food decreases leading to a significant decrease in Bulk Food Price. Then, other price levels are affected by Bulk Food Price level and all three prices decrease.

The resulting price behavior along the agricultural value chain for the best technology investment policy, which turns out to be improving processing yield according to our results, can be seen in Figure 6.12. We can observe that, under this policy, the widening gap among the price levels in the special case as seen in Figure 6.9 is narrowed

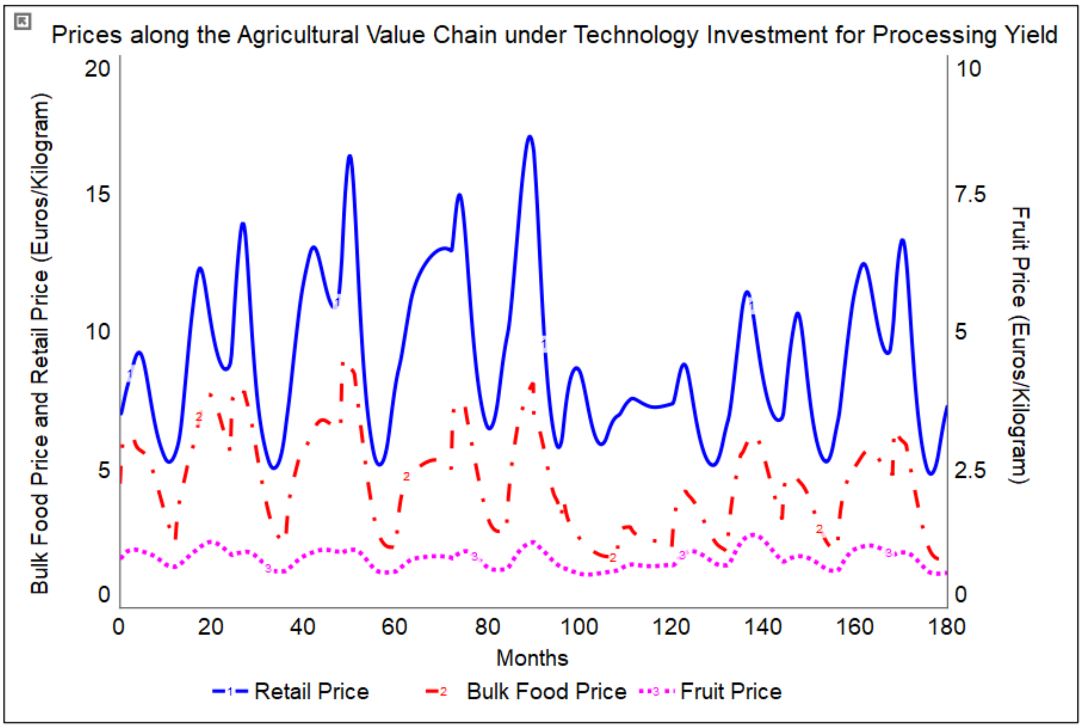

Figure 6.12: Prices along the Agricultural Value Chain under the Policy of Technology Investment in Processing Yield

down.

For our variable setting in the model, we observe that processing yield improvement policy gives the best results in terms of mitigating price fluctuations. One can argue that this result is somehow intuitive since the given budget of 25 M Euros leads to the highest percentage of improvement, 35%, in processing yield. With this argument in mind, we make an additional set of experiments without limiting the budget and holding the percent improvement the same for all policies. The details of the policies are given in Table 6.16 and the resulting retail price levels compared to the base case and the special case can be seen in Figure 6.13.

When the same high percent of improvement is implemented to both share of bearing trees and fruits per tree, unexpectedly, undesirable effects are observed to result in price. Due to higher increases in fixed costs of operations, that much improvement in these areas leads to much sharper price shocks (see the price levels around months 120 and 150 in Figure 6.13). These results show us that higher improvement percentages do not indicate the policy being more successful in mitigating the price fluctuations.

Table 6.16: Additional Technology Investment Policies in the Special Case

Policy Area	Improvement	Investment Cost
3 - Processing Yield	35%	35% increase in Fixed Cost of Processing
4 - Share of Bearing Trees	35%	35% increase in Fixed Cost of Harvesting
5 - Fruits per Tree	35%	35% increase in Fixed Cost of Harvesting

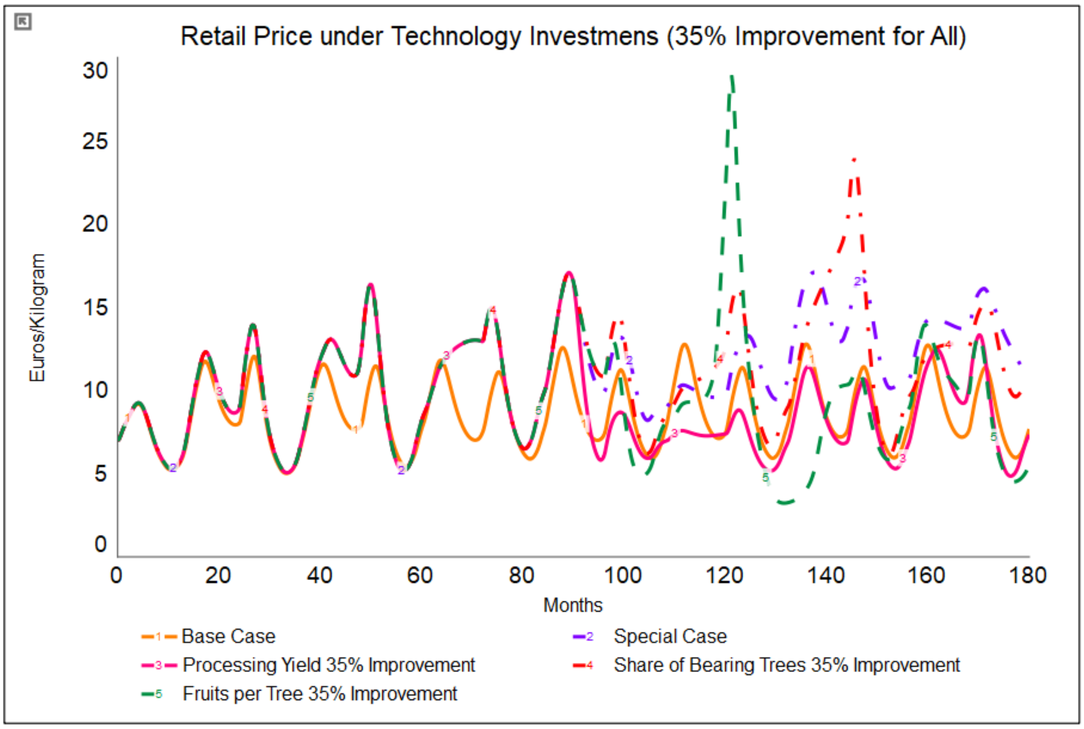

Figure 6.13: Retail Price for (1) Base Case, (2) Special Case without Policy Implementation and (3, 4, 5) Special Case under Various Technology Investment Policies with the Same Improvement Percentage

6.5.2 Improvements in Financial Aids in the Special Case

Similar to the technological investment policies, the same investment of 25 M Euros per year between months 90 and 180 corresponds to the improvements in financial aids as in Table 6.17. The main difference between the technological investment

Table 6.17: Financial Aid Improvement Policies in the Special Case

Policy Area	Improvement
1 - Financial Aids for Planting	25% increase in Financial Aids for Planting
2 - Financial Aids for Harvesting	15% increase Financial Aids for Harvesting
3 - Financial Aids for Processing	30% increase Financial Aids for Processing

policies and financial aid improvement policies is that, in financial aid improvement policies, the additional financial aid is directly given to the regarding stakeholders; hence it does not affect the costs directly.

The resulting retail prices of the three financial aid improvement policy runs compared to the base case and the special case can be found in Figure 6.14.

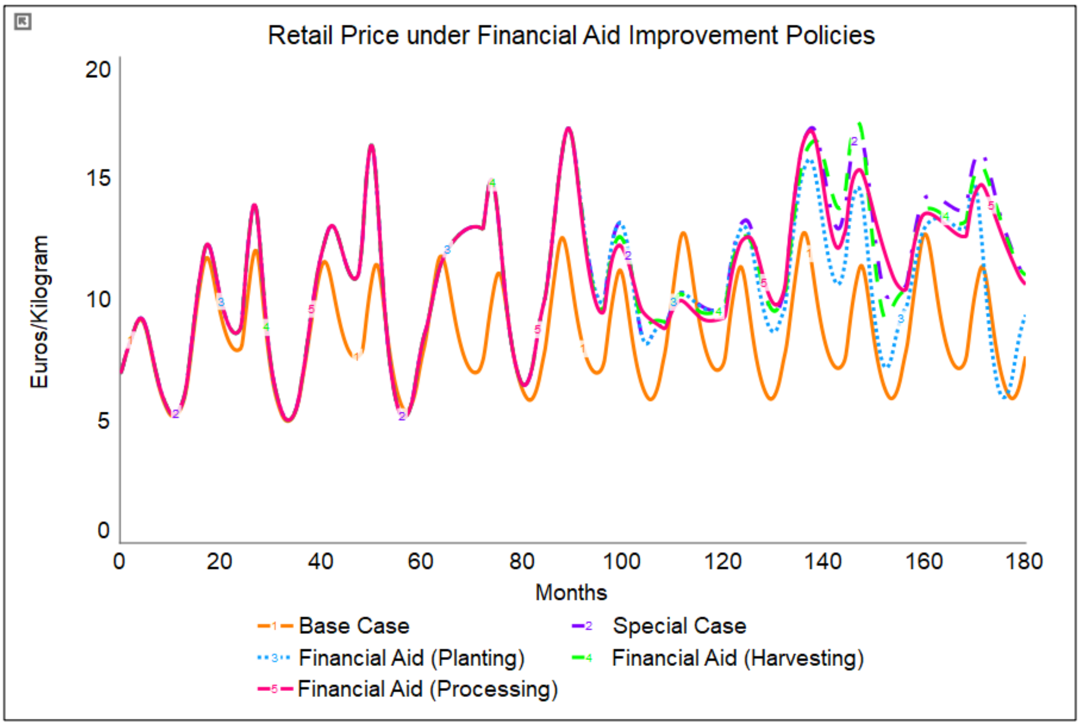

Figure 6.14: Retail Price for (1) Base Case, (2) Special Case without Policy Implementation and (3, 4, 5) Special Case Under Various Financial Aid Improvement Policies

One prominent observation in Figure 6.14 is that the improvement in Financial Aid for Planting performs the best in mitigating price shocks through the time horizon. The resulting price behavior along the agricultural value chain can be found in Figure 6.15. Even though Planting process is at the beginning of the value chain and retail price emerges at the end of the chain, this policy leads the retail prices to gain a decreasing trend within a short time upon implementation of the policy. The reason behind the performance of this policy can be summarized as follows: increasing financial aid for improvement naturally increases planting rate and hence expands the capacity of the whole system. Then, supply of fruit, bulk food and packaged food and hence inventory coverages increase along the whole chain. As a response to increasing export and domestic demand in the special case, capacity expansion due to financial aid improvement performs better in mitigating price fluctuations.

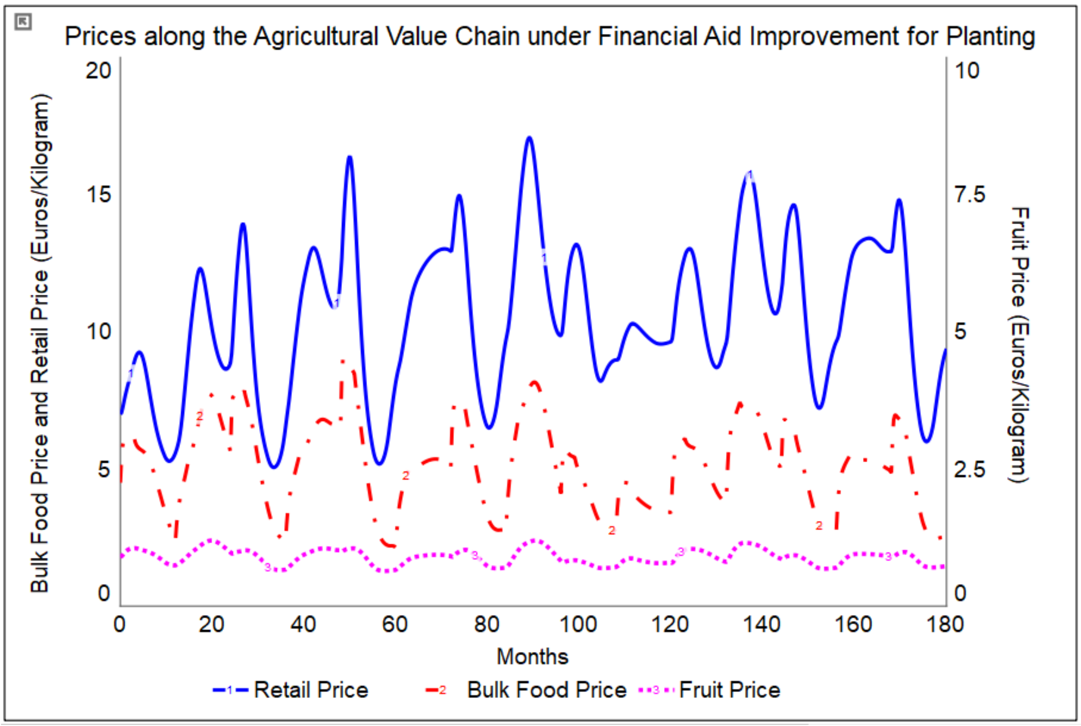

Figure 6.15: Prices along the Agricultural Value Chain under the Policy of Financial Aid Improvement for Planting

As it is mentioned before, policy parameters are determined depending on the planting, harvesting, processing and packaging realizations between months 0 and 90. Hence, the realization of the investments and the paid amount of yearly financial aids between months 90 and 180 can be slightly different. In Table 6.18, we can see the resulting retail price statistics and the average additional cost per year spent for each policy alternative.

Table 6.18: Summary of Policy Analysis Results

Run / Policy (Improvement%)	Resulting Retail Prices (Euros/kg) (Avg, St Dev)	Cost (Euros)
Base Case	(8.73, 1.97)	-
Special Case	(12.37, 2.38)	-
Technological Investment Policies		
1 - Share of Bearing Trees (10%)	(12.27, 2.71)	24.3 M
2 - Fruits per Tree (10%)	(11.43, 3.17)	26.5 M
3 - Processing Yield (35%)	(8.11, 2.20)	25.4 M
4 - Share of Bearing Trees (35%)	(11.88, 3.60)	88.0 M
5 - Fruits per Tree (35%)	(9.35, 4.46)	113.7 M
Financial Aid Improvement Policies		
1 - Financial Aid for Planting (25%)	(11.04, 2.35)	26.3 M
2 - Financial Aid for Harvesting (15%)	(12.19, 2.32)	23.9 M
3 - Financial Aid for Processing (30%)	(12.02, 2.08)	26.5 M

The counter-intuitive result of this comparative analysis is that, even though technological improvements increase the fixed costs while financial aids are direct payments to the stakeholders, technological improvement policies perform better than financial aid improvement policies in terms of the average retail price.

6.6 Discussion

The system dynamics model we have constructed to understand the price dynamics along the agricultural value chains is utilized mainly to illustrate the results of various policy interventions applied in different stages of the chain. These results are shown through the behavior of the retail price under the special case which leads to price fluctuations and several policies for mitigation.

Considering the results of the quantitative analysis conducted with the agricultural value chain model, we can point out three major implications for the policy makers:

- **In policy decisions for agricultural value chain interventions, the size of the budget does not necessarily imply the magnitude of the improvement that may result.** We illustrate that similar amounts of investments may not provide similar results in the mitigation of price shocks. For our specific parameter setting, for instance, technology investment policies perform better than the financial aid improvements along the value chain. Among all options, investing in improving processing yield gives the best results.
- **In line with the implication above, similar percent changes in policy parameters do not necessarily provide similar results in terms of value chain improvement.** On the contrary, some improvement policies may affect some critical structures along the chain and trigger another more severe price shocks.
- **Making investments and interventions to the "weakest" stage of the agricultural value chain does not necessarily provide the best results**. In some traditional agricultural value chain analysis and intervention projects, the weakest stage of the value chain is determined first and the value chain improvement policies focus on that stage. Yet, we show that one intervention to a stage of the chain may result in different reactions along the other stages. For instance, it is surprising to have observed that improvements in financial aids to planting process, which is the beginning stage, performs the best in mitigating retail prices at the end of the chain. That is, the agricultural value chains are to be treated and analyzed as a whole for the best policy decisions.

Although these observations seem to be valid for our synthetic parameter set, they actually shed some light on the importance of dynamic models for policy analyses in real-life agricultural value chains.

Together with its benefits, the numerical study presented in this chapter has got some limitations: First of all, although it includes nine different modules and hundreds of variables, this model is still a simplification of a specific real-world agricultural value chain. Improvement and modification of function structures, addition of new decision rules and variables seem to be necessary. In Chapter 7, we apply this model to a real world case, the olive oil value chain in Turkey and make additional analyses in the following chapters. Another limitation is about the parameter set used in the model. In our parameter setting, we use several constants and simple linear functions, which are obviously more complex in their real world counterparts. These parameter choices are also revised accordingly in the model application step. One important limitation is about the choice of metrics in illustrating the results. For this study, we mainly focus on the mitigation of price fluctuations, especially retail prices and present their resulting average and standard deviation values. For our stylized setting, these two metrics and graphical displays seem to be adequate to understand the magnitude of price fluctuations. Yet, in real world application step, other metrics such as consumer surplus, producer surplus, earnings of stakeholders, etc. are analyzed to see the entire effects of the policies.

CHAPTER 7

APPLICATION OF THE AGRICULTURAL VALUE CHAIN MODEL FOR THE OLIVE OIL VALUE CHAIN IN TURKEY

In this chapter, we provide the application and adaptation procedure of the generic agricultural value chain model for a real world case, namely the olive oil value chain in Turkey. For each module we present and explain:

- Data analysis with available real world data,
- Structural modifications made in the model formulations (if any),
- Parameter settings for the exogenous variables,
- Calibration and partial-model test results.

7.1 Overview of the Application Procedure

The application of the generic model to olive oil value chain in Turkey is conducted based on a module-by-module manner. The main rule of thumb followed in the parameter setting and the calibration for each module is handling each module separately while leaving other modules intact. It is obvious that all modules in the model are interrelated. Yet, during the parameter setting and calibration process, only the module that is calibrated is kept active while the other modules are deactivated. The inputs created by the other modules are fed into the calibrated module depending on their historical occurrences. In other words, partial calibration procedure is followed and partial test results are considered.

Throughout the chapter, the parameter setting and partial calibration process is presented with the following sections:

In **Data Analysis and Implications** section, available historical data related with the dynamics of the module are presented. If any data availability issues are experienced, then the remedies to overcome these issues are also explained. The implications obtained from the available data and major points on the dynamic hypothesis within the module are stated.

It is to be noted that the Agricultural Commodity Value Chain Model presented in Chapter 5 is a simplified version of the real world agricultural value chain which we call as the special case. Hence, in the adaptation of it to the olive oil value chain in Turkey, several improvements and modifications are needed in analytical and mathematical relationships. In **Model Structure Improvements for Application** sections, the improvements and modifications made in the structure of the functions within the modules are presented.

In **Parameter Setting and Module Calibration** section, first, the sources of parameters are presented. For one set of these parameters, data sources are already available. Yet, for another set of parameters, the data are not available, hence they are to be assumed based on the knowledge of the real system. Other than these, there is another set of parameters, values of which are neither available in data sources nor appropriate to make assumptions on their magnitudes, for instance, "Sensitivity of A to B" type of exogenous variables are appropriate examples for this set of parameters, we can make predictions on their feasible regions, but in order to set their magnitudes, we need to make detailed quantitative analysis on historical data. Unfortunately, parameters of this type are generally correlated and interrelated with the other parameters. Hence, we have to consider the feasible regions of these parameters simultaneously and solve an optimization problem which minimizes the "error between the historical data points and the model results". This problem is called the "automated partial calibration" problem. For each module, we write down the **Calibration Problem** with its objective function and constraints as the feasible regions of the calibrated parameters. The calibration problem in each module is solved with the integrated optimization module of Stella Architect, and the method for optimization is differential evolution heuristic, i.e. genetic algorithm.

During the parameter setting and calibration, we make a set of iterative tests and controls for the credibility of the model. For these tests and controls, a **Calibration Checklist** is prepared as a compilation of rules and guidelines given in Barlas (1996), Oliva (2003), and Sterman (2000):

Calibration Checklist:

- Statement and Compatibility of Dynamic Hypothesis and Reference Mode
- Usage of all available knowledge about the system parameters
- Building the smallest possible calibration problem
- Feasibility of the parameter
- Consistency of the parameter
- Calibration of the initial conditions where needed
- Searching for alternative structures when needed
- Documentation of the calibration problem

This calibration checklist is controlled and necessary actions are taken iteratively for each module. After the calibration checklist items are satisfied, parameters are imported to the model and the partial run results of the module are investigated. Mean Absolute Percent Error (MAPE) between the historical and model generated data are reported. In addition to MAPE results, graphical investigation of dynamic behaviors is conducted. The partial calibration process for the module is completed as the convincing partial test results are achieved. The details of model validity test results for the complete model are presented in Chapter 8.

In the following sections, the application stages reviewed above are described for each module.

7.2 Olive Tree Planting

7.2.1 Data Analysis and Implications

In order to understand the real world behavior of Olive Tree Planting in Turkey, the relevant data are available on an annual basis. The data of some key variables from 2007 to 2017 in Turkey are graphed in Figure 7.1.

The observations gathered from these graphs can be summarized as follows:

- Total number of trees and the number of mature trees are increasing while the number of young trees is decreasing.
- Depending on the data on the change in total number of trees, planting rate should have been larger than zero in almost every year except one year only, 2011. Hence, planting operations should have occurred in almost every year.
- For Planting operations to occur each year, Desired Tree Stock Adjustment Time and Planting Adjustment Time are to be mathematically more than one year, at least 3 or 4 years.
- We observe that total number of trees is increasing. Surprisingly, this occurs despite the decreasing fruit prices and increasing planting costs. These observations may be due to either of the two possibilities or both:
    1. The Effect of Financial Supports is stronger than the Effect of Fruit Price and the Effect of Planting Costs.
    2. Despite the decreasing fruit prices and increasing planting costs, their effects end up emerging as being larger than "1" at some points, which indicates that their reference levels are different from their values at t_0.

7.2.2 Model Structure Improvements for Application

In order to reflect the olive tree stock dynamics in Turkey, improvements and modifications that are deemed necessary in the model structure can be itemized as follows:

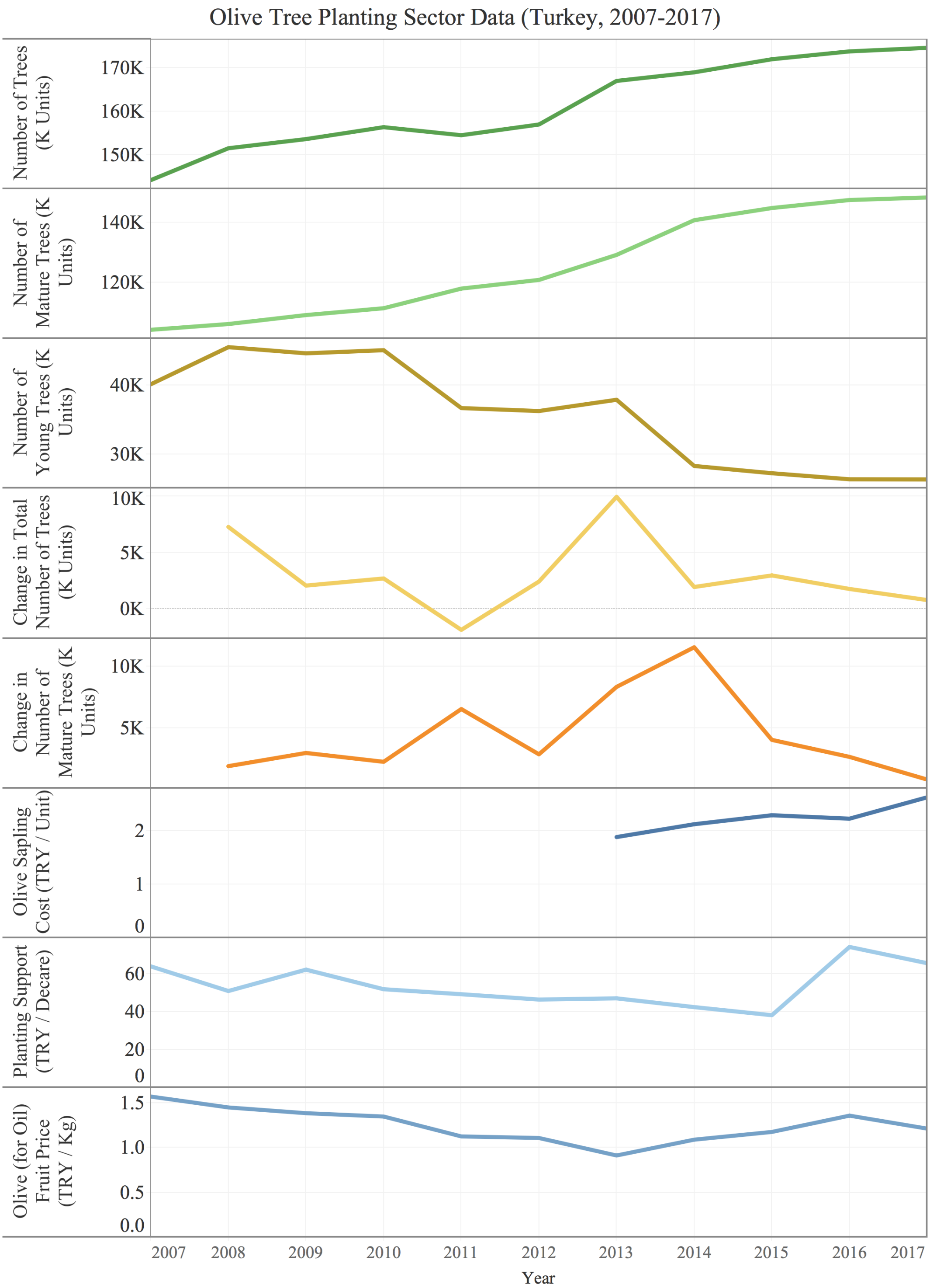

Figure 7.1: Olive Tree Planting Sector Data in Turkey, 2007-2017

- For Reference Tree Stock Level, instead of using the constant reference value of Mature Trees at t_0, we use Mature Trees (t) and make Reference Tree Stock Level update itself with the mature tree stock level then.

- In generic agricultural value chain model, Maturation Rate is modeled as a third order delay function of Planting Rate with Maturation Time. In initial parameter setting runs, we observe that this structure is not able to replicate the historical occurrences of the number of young trees and the number of mature trees in Turkey. Then, as an alternative structure, Maturation of Young Trees is explicitly modeled as a third order delay of Planting Rate with three different Maturation Time delays (Maturation Time 1, Maturation Time 2, Maturation Time 3). Hence, in order to assign different Maturation Times, we explicitly model a third order delay structure with three Young Tree Stocks (Young Trees 1, Young Trees 2, Young Trees 3) and assign different maturation delay times.

- Death Rate of Young Trees and Death Fraction of Young Trees are added to the model to represent the death of young trees before maturation.

- Effect of Fruit Price on Tree Stocks is redefined as Effect of Fruit Profitability on Tree Stocks. In that way, profitability of harvesting operations and changes in Variable Cost of Harvesting and Financial Supports for Harvesting are reflected to decisions about olive tree stocks.

- Effect of Growing Costs on Desired Tree Stock Level is added to the model as an input of Desired Tree Stock Level. In that way, the effect of operating cost of each additional olive tree capacity is reflected to decisions about olive tree stocks.

- Maximum Effect of Planting Costs is added to the model to prevent the model from calculating Desired Tree Stock Level as going towards infinity under extreme conditions.

As the structural improvements and modifications are completed, Direct Structure Tests are repeated. After the structure is settled, we proceed with parameter setting and module calibration.

7.2.3 Parameter Setting and Module Calibration

The regarding parameter settings in Olive Tree Planting Module can be summarized as follows:

- For the initial value of the Mature Trees and Young Trees stocks, the historical data of olive tree stock in 2007-2008 harvest season are considered.

- Mature Trees do not only decrease depending on their natural life time, but they can be removed due to several reasons. That is why their outflow is labeled as “Death or Removal Rate”. Hence, Life Time parameter is expected to be shorter than the natural lifetime of olive trees, which is approximately 500 years. In order to conserve physical laws depending on data analysis, Life Time parameter is set to 1200 months.

- As it is observed in initial data analysis, Desired Tree Stock Adjustment Time is assumed to be 60 months and Planting Adjustment Time is assumed to be 48 months.

- Financial Supports for Planting and Planting Costs are directly gathered from their reference sources and embedded to the model as external variables. Their time series can be seen in Figure 7.1 above. The missing points of Planting Costs are completed according to the trend of available Planting Cost data.

- Planting Period is defined according to the field information, that is, olive saplings are planted during October-March.

- Minimum Effect of Financial Supports is assumed to be 0.95. Since Financial Supports for Planting are additional benefits to increase the tree stock level, very low levels of support do not have a rigid decreasing effect. Hence, Minimum Effect of Financial Supports is determined as being slightly smaller than 1.

- Maximum Effect of Planting Costs is set to 10, which is an arbitrarily large number for this effect. It is only effective under extreme conditions and prevents the model from calculating Desired Tree Stock Level as going towards infinity.

- Death Fraction of Young Trees is set to 0.003 1/Month as a result of several search runs with an increment of 0.001.
- Maturation Time 1-2-3, Sensitivity and Reference values are determined simultaneously as the solution of the minimization problem where the objective function is the "sum of square errors between the young trees stock values generated by the model and the historical data of young trees" plus "sum of square errors between the mature trees stock values generated by the model and the historical data of mature trees". The details of calibration problem can be seen below.

Calibration Problem for Planting:

Minimize
$\sum (\text{Young Trees}_M - \text{Young Trees}_H)^2 + \sum (\text{Mature Trees}_M - \text{Mature Trees}_H)^2$
subject to

$$6 \leq \text{Maturation Time 1} \leq 12$$
$$12 \leq \text{Maturation Time 2} \leq 36$$
$$36 \leq \text{Maturation Time 3} \leq 60$$
$$0.1 \leq \text{Sensitivity of Tree Stocks to Fruit Price} \leq 0.5$$
$$-0.5 \leq \text{Sensitivity of Tree Stocks to Planting Costs} \leq -0.1$$
$$-0.5 \leq \text{Sensitivity of Tree Stocks to Growing Costs} \leq -0.1$$
$$0.15 \leq \text{Sensitivity of Tree Stocks to Financial Supports} \leq 0.5$$
$$0.20 \leq \text{Reference Growing Cost} \leq 0.25$$
$$10 \leq \text{Reference Financial Supports for Planting} \leq 35$$
$$0.4 \leq \text{Reference Planting Cost} \leq 0.9$$

Calibration Checklist:

- **Statement and compatibility of Dynamic Hypothesis and Reference Mode:** After the calibration process, we observe an increasing number of mature trees, a decreasing number of young trees, and a positive planting rate despite increasing planting prices and decreasing fruit prices. Planting rate increases with financial supports and fruit prices, and decreases with planting costs.

- **Usage of all available knowledge about the system parameters:** For Planting module calibration problem; costs, financial supports and fruit prices are used as the same as their historical occurrences.

- **Building the smallest possible calibration problem:** We only consider minimizing the error in mature trees and young trees via determining the maturation times and effect of inputs.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** Total maturation time reflects our knowledge on the real-world system. We know that it takes an olive sapling plantation 5 to 7 years to become fully productive (European Commission, 2012). As the result of the calibration process, total maturation time becomes 6.52 years. Effect of Financial supports is higher than the other effects as expected. Planting rate happens to be always positive in every season as expected.

- **Calibration of initial conditions:** Initial conditions of tree stocks are not required to be calibrated, since historical data are used in 2007-2008 harvest season. Reference values of effect functions are calibrated.

- **Search for alternative structures:** Model structure improvements are done as explained in section 7.2.2.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.1.

After the parameter settings, the resulting partial model test result for the number of Young Trees and number of Mature Trees can be seen in Figures 7.2 and 7.3, respectively. MAPE between these two data sets of Mature Trees is 2.5%, and MAPE between these two data sets of Young Trees is 4.4%. As important as MAPE values, model results, especially the ones of Mature Trees, follow almost the same behavioral pattern with their historical data sets.

Table 7.1: Planting Variables - Parameter Settings

Converter (Unit)	Reference
Mature Trees (t_0) = 104,219 (K Units)	TÜİK
Young Trees 1 (t_0) = 13,370 (K Units)	TÜİK
Young Trees 2 (t_0) = 13,370 (K Units)	TÜİK
Young Trees 3 (t_0) = 13,370 (K Units)	TÜİK
Financial Supports for Planting = Historical Graphical Data (TRY / Decare)	TÜİK
Planting Costs = Historical Graphical Data (TRY / Unit)	MAF
Planting Period = IF ((TIME MOD 12) >= 0 AND (TIME MOD 12) < 6) THEN 1 ELSE 0 (Dimensionless)	Definitional
Life Time = 1200 (Months)	Assumed
Minimum Effect of Financial Supports = 0.95 (Dimensionless)	Assumed
Maximum Effect of Planting Costs = 10 (Dimensionless)	Assumed
Planting Adjustment Time = 48 (Months)	Assumed
Maturation Time 1 = 9.85 (Months)	Calibrated
Maturation Time 2 = 22.54 (Months)	Calibrated
Maturation Time 3 = 45.86 (Months)	Calibrated
Death Fraction of Young Trees = 0.003 (1/Months)	Assumed
Desired Tree Stock Adjustment Time = 60 (Months)	Assumed
Reference Financial Supports for Planting = 10 (TRY / Decare)	Calibrated
Reference Planting Costs = 0.9 (TRY / Unit)	Calibrated
Reference Growing Cost = 0.25 (TRY / Unit)	Calibrated
Sensitivity of Tree Stocks to Financial Supports = 0.175 (Dimensionless)	Calibrated
Sensitivity of Tree Stocks to Fruit Price = 0.1 (Dimensionless)	Calibrated
Sensitivity of Tree Stocks to Growing Costs = -0.1 (Dimensionless)	Calibrated
Sensitivity of Tree Stocks to Planting Costs = -0.209 (Dimensionless)	Calibrated

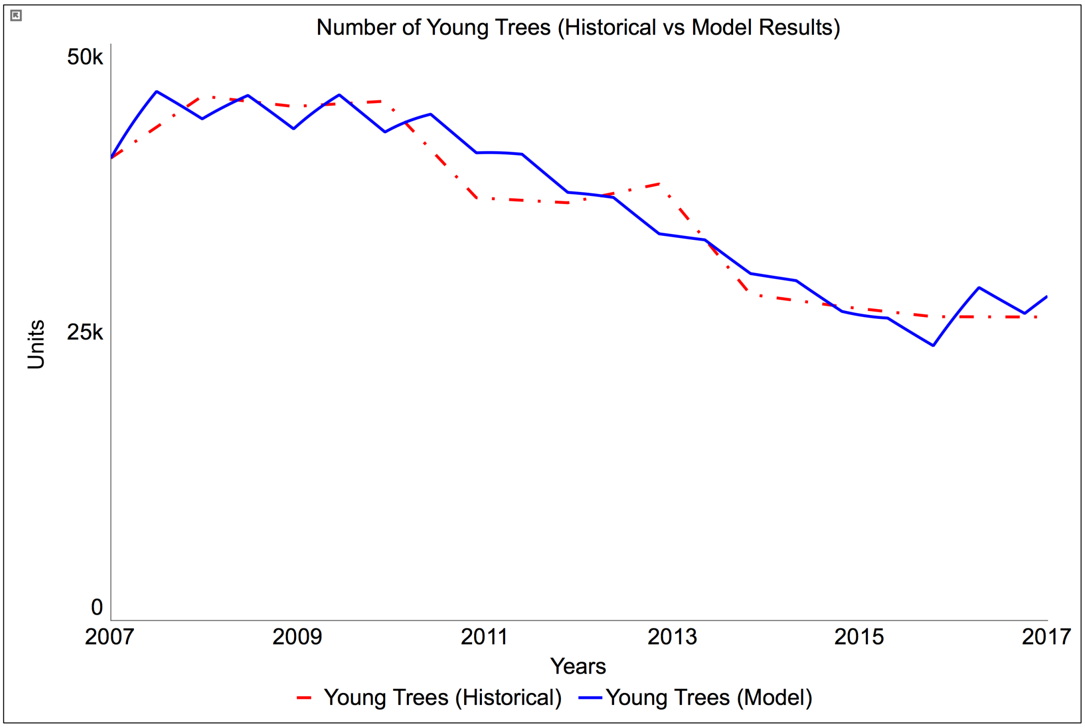

Figure 7.2: Historical Values and Model Results for Young Trees (2007-2017)

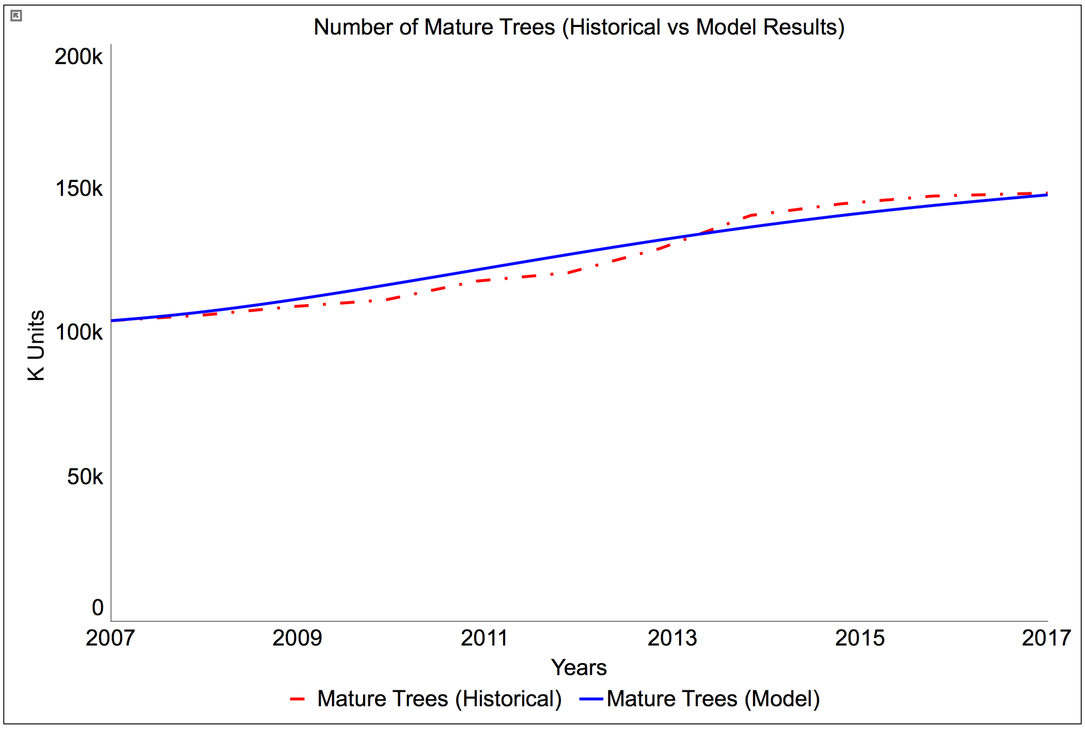

Figure 7.3: Historical Values and Model Results for Mature Trees (2007-2017)

7.3 Olive Harvesting

7.3.1 Data Analysis and Implications

Similar to Olive Tree Planting module, the relevant data on Olive Harvesting in Turkey are available on an annual basis. The data of some key variables from 2007 to 2017 in Turkey are graphed in Figure 7.4. The observations gathered from these graphs are explained below:

- Olive Harvest Amount has an increasing trend.
- Olives for Oil follows a similar pattern to Olive Harvest Amount and shows an increasing trend, whereas Olives for Table Olives is independent of Olive Harvest Amount and follows a more stationary behavior. Hence, Share of Olives for Oil has a similar pattern to Olive Harvest Amount.
- Fruit per Mature Tree is not alternating in consecutive years; but it is not completely random. The detailed data analysis reveals that, with the increasing number of trees, alternation period has elongated to 3-4 years.

7.3.2 Model Structure Improvements for Application

In application of Olive Harvesting module, a number of structural improvements and modifications are deemed necessary depending on data availability:

- **Fruits per Mature Tree:** In the olive oil case in Turkey, no distinct data or information on Share of Bearing Trees and Fruits per Bearing Tree are provided. The only available data are Fruits per Mature Trees, calculated via dividing the Total Harvest Amount by Total Number of Bearing Trees. Hence, the model is modified accordingly; an aggregate variable **Fruits per Mature Tree** is added to the model as an exogenous variable.

  When we investigate the behavior of Fruits per Mature Tree, we find out that the data points are not completely random; rather they follow an oscillating

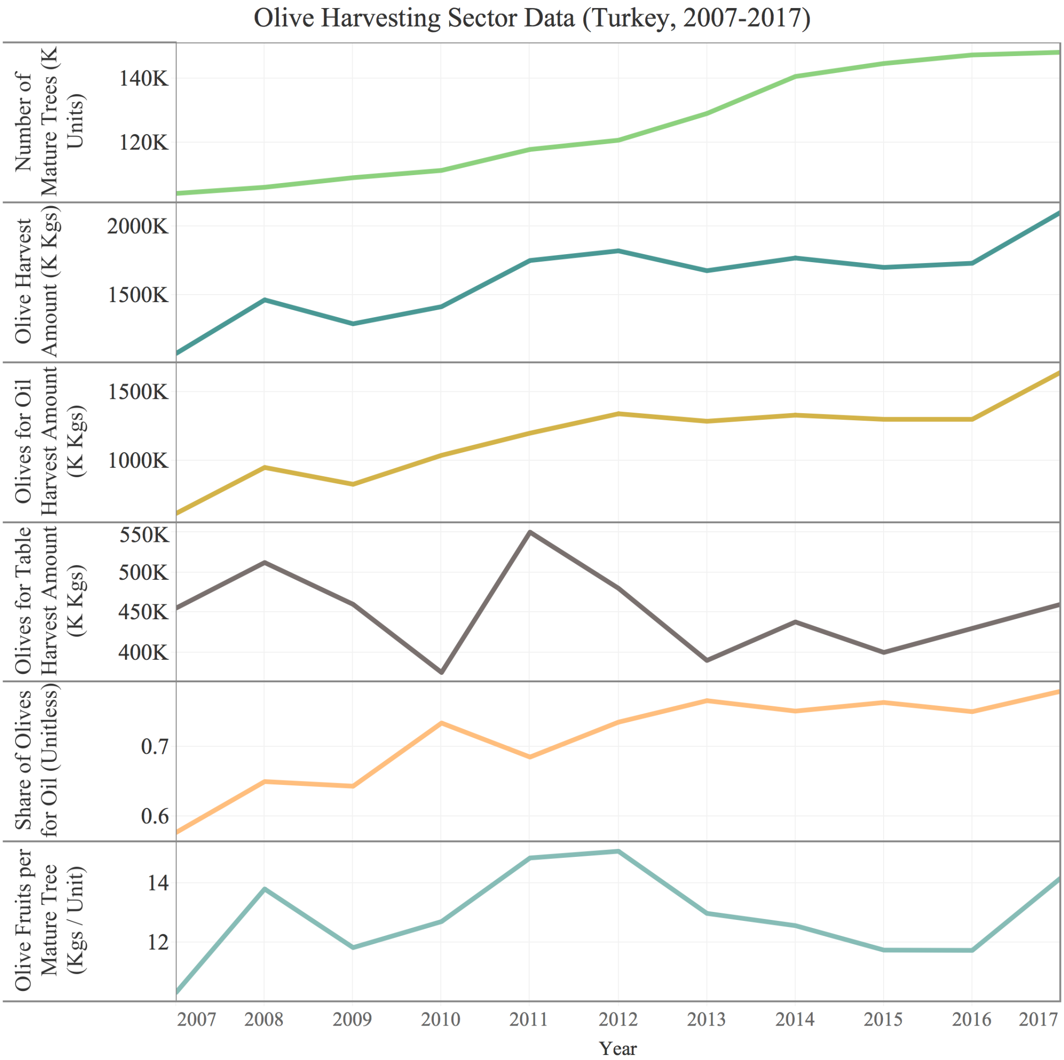

Figure 7.4: Olive Harvesting Sector Data in Turkey, 2007-2017

behavior for longer periods of 3-4 years. A forecasting model with triple exponential smoothing method fits well to the historical data, with a season length of 3 years. For future occurrences of Fruits per Mature Tree, this forecasting model can be utilized if required.

- **Share of Fruits for Processing:** Data analysis shows that the relationship between Harvest Rate and Olive Usage Rate for Olive Oil is slightly different from the existence of a constant Share of Fruits for Olive Oil. In generic Agricultural Value Chain Model, we define the relationship as:

  Fruit Usage Rate for Processing = Harvest Rate * Share of Fruits for Processing.

  Yet, the data analysis shows that the relationship is still linear, but the function structure requires a constant term which is an indicator of the Fruit Usage for Other Means. As we have mentioned earlier, we have only yearly total data for total olive harvest and total olive amount used for olive oil. The analysis conducted with the yearly data shows that the relationship between these two variables is as follows:

  Total Yearly Olive Used for Olive Oil Processing = (0.9851 * Total Harvest Amount) - 425,957.

  Total Yearly Olive Used for Other Means = (0.0149 * Total Harvest Amount) + 425,957.

  Yet, in the model, we need the usage of olives for oil in a "rate" form, rather than a yearly total number. Additionally, we know that olives are so perishable that they should be processed immediately, which means that processing operations should be completed within the Harvest Period. Then, in adaptation to Olive Oil Value Chain, we modify the relationships as a rate function as such:

  Olive Usage Rate for Other Means = IF (425,957 / Harvest Time) + (0.0149 * Harvest Rate) $\leq$ 0.5*Harvest Rate THEN (425,957 / Harvest Time) + (0.0149 * Harvest Rate) ELSE 0.5 * Harvest Rate.

  Olive Usage Rate for Olive Oil Processing = Harvest Rate - Olive Usage Rate for Other Means.

These two functions indicate that a large constant portion plus a small multiplicative portion of harvest is used for other means during the harvest period and the rest is used for processing olive oil. The "IF ... ELSE ..." structure indicates that at least half of the total olive harvest amount is used for oil processing. This information is obtained from the historical data: Even when the harvest amount is very small, the lowest value of Share of Olives for Oil has been observed as 0.58 since 1988.

- Total Harvest Amount and Perceived Harvest Amount structures are simplified. Instead of using stock-and-flow structures, built-in SMOOTH function is used to calculate Perceived Harvest Amount.

7.3.3 Parameter Setting

The regarding parameter settings in Olive Fruit Harvesting module can be summarized as follows:

- Initial value for Harvest Amount is set to 0 since it is an information stock to calculate the annual harvest amount.
- Fruits per Mature Tree is calculated as the ratio of historical olive harvest amount to the historical number of mature trees based on TÜİK database.
- Harvest Time is taken as 3 months in a year.
- Harvest Perception Time is assumed to be 2 months.
- Reference Harvest Amount is not directly used in Harvesting module and it is calibrated during the calibration of Fruit Price Setting module.
- Reference Harvest Utilization is assumed to be 1. According to the information gathered from the interviews with the relevant stakeholders, the expected behavior in the harvesting stage is collection of all available fruits on the trees. Yet, in case of an unexpected increase in Variable Harvesting Costs (hence an unexpected decrease in Profitability of Harvesting), a small portion of olives on the trees may not be collected. Hence we set Reference Harvest Utilization

Table 7.2: Harvesting Variables - Parameter Setting

Converter	Reference
Harvest Amount (t_0) = 0 (Kg)	Definitional
Fruits per Mature Tree = Historical Graphical Data (Kg / Units)	TÜİK
Harvest Time = 3 (Months)	Field Information
Harvest Perception Time = 2 (Months)	Assumed
Reference Harvest Amount = 1,014,243 (K Kg)	Calibrated
Reference Harvest Utilization = 1 (Dimensionless)	Field Information
Sensitivity of Harvest Rate to Profitability = 0.15 (Dimensionless)	Assumed

to 1 and remind that Harvest Utilization is defined as MIN(Harvest Period * Reference Harvest Utilization * Effect of Profitability on Harvest Utilization, 1)

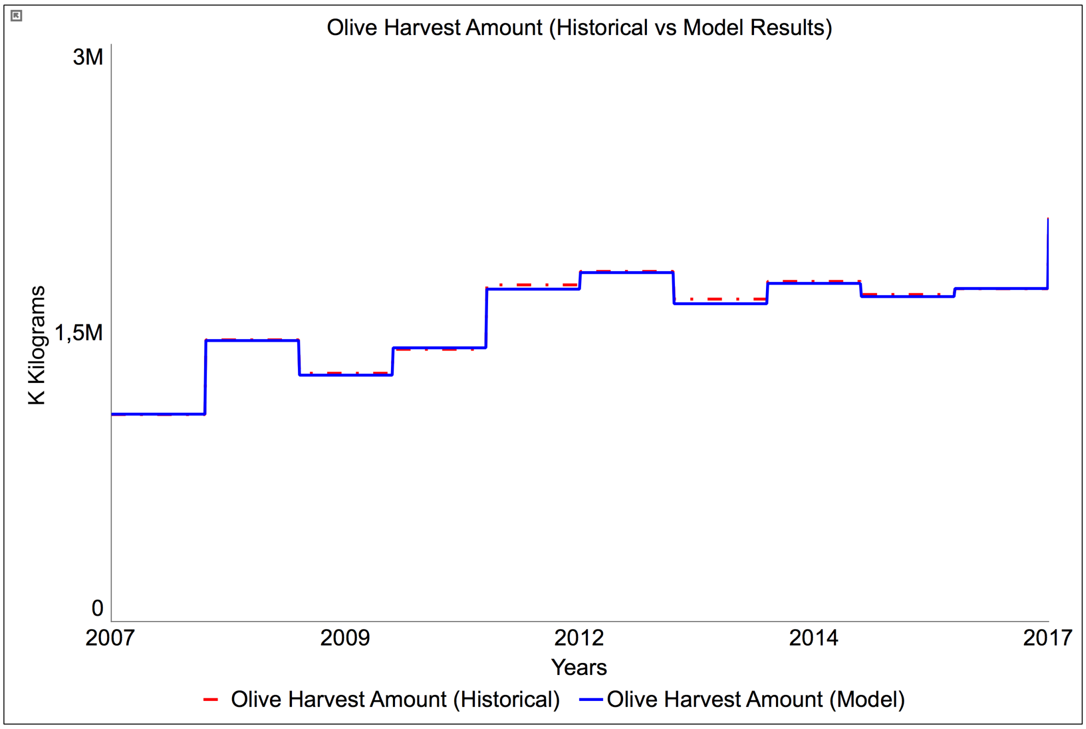

Figure 7.5: Historical Values and Model Results for Olive Harvest (2007-2017)

- Sensitivity of Harvest Rate to Profitability is known to be slightly effective, hence it is set to a small number like 0.15.
- Building an automated calibration problem is not required in Harvesting module since all parameters are either assumed or definitional.

For the complete parameter settings and their references, see Table 7.2.

After the parameter setting, the resulting partial model test result for the Olive Harvest Amount can be seen in Figure 7.5. MAPE between model generated results and historical values is only 0.5%.

7.4 Olive Oil Processing

7.4.1 Data Analysis and Implications

Similar to Olive Tree Planting and Olive Harvesting modules, the relevant data on Olive Oil Processing in Turkey are available on an annual basis. The data of some key variables from 2007 to 2017 in Turkey are graphed in Figure 7.6. The observations gathered from these graphs are explained below:

- Olives for Oil and Olive Oil Processing Amount have increasing trends.
- Olive Oil Processing Yield is not stationary, but it is not completely random. The detailed data analysis reveals that, similar to Fruits per Mature Tree, Olive Oil Processing Yield has trend, level and seasonality components and fits well to a triple exponential smoothing model with a season length of 6 years.
- Olive Fruit Price, which is the raw material cost of Olive Oil Processing stage, is negatively correlated with Processing Support.

7.4.2 Model Structure Improvements for Application

In application of Olive Oil Processing module, only a few modifications are made for calculation purposes:

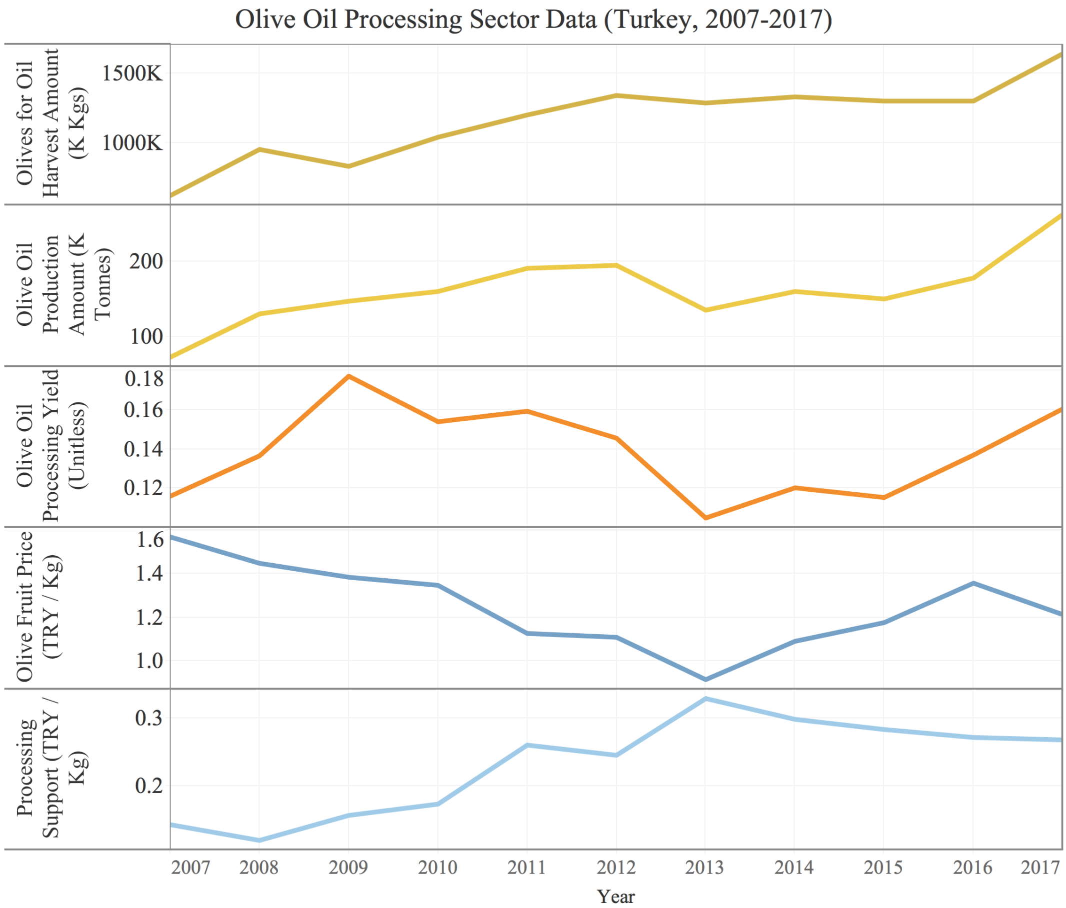

Figure 7.6: Olive Oil Processing Sector Data in Turkey, 2007-2017

- In order to keep record of long term perceived supply/demand ratio of the whole chain, we add two structures to the Olive Oil Processing Module: Average Bulk Food Supply and Average Bulk Food Demand. As their names imply, Average Bulk Food Supply is used to calculate annual average processed bulk food with Bulk Food Supply Averaging Time of 12 months. Similarly, Average Bulk Food Demand is used to calculate annual average export demand and domestic demand with Bulk Food Demand Averaging Time of 12 months. Their formulations are as follows:
  Average Bulk Food Supply = SMTH1(Total Bulk Food , Bulk Food Supply Averaging Time)
  Average Bulk Food Demand = SMTH1((Rate of Bulk Food Export Quantity Demanded + Rate of Packaged Food Export Quantity Demanded + Demand)*Bulk Food Demand Averaging Time, Bulk Food Demand Averaging Time)

7.4.3 Parameter Setting

The regarding parameter settings in Olive Oil Processing module can be summarized as follows:

- Initial value for Processed Bulk Food Inventory is set to 30,000 K Kg during the automated calibration process of Packaging module. The details are given in section 7.5.

- Bulk Food Export Time is assumed to be 1 month.

- Bulk Food Demand and Bulk Food Supply Averaging Times are assumed to be 12 months, since the perceptions on average olive oil supply and demand is expected to be updated with that rate.

- Processing Time is set to be equal to Harvesting Time which is 3 months in a year, since olive fruit is so perishable that it should be processed as soon as possible after Harvesting.

- Processing Yield is calculated as the historical data for processed olive oil amount divided by the historical data for olives for oil amount based on TÜİK and IOC databases.
- Reference Process Utilization is assumed to be 1 as similar to Reference Harvest Utilization. The expected behavior in the processing stage is extraction of all available harvested olives for oil. Yet, in case of an unexpected increase in Variable Processing Costs (hence an unexpected decrease in Profitability of Olive Oil Processing), a small portion of olives harvested may not be processed. Hence we set Reference Process Utilization to 1 and remind that Process Utilization is defined as MIN(1, Effect of Profitability on Processing Utilization * Reference Process Utilization).
- Sensitivity of Process Utilization to Profitability is known to be slightly effective, but less effective than Sensitivity of Harvest Rate to Profitability, hence it is set to a small number which is 0.10.
- Building an automated calibration problem is not required in Processing module, since all parameters are either assumed or used as their historical occurrences.

For the complete parameter settings and their references, see Table 7.3.

After the parameter setting, the resulting partial model test result for the Olive Oil Processing Amount can be seen in Figure 7.7. MAPE between model generated results and historical values is only 0.4%.

7.5 Olive Oil Packaging

7.5.1 Data Analysis and Implications

The data analysis conducted for Packaging module is different from the other modules. Olive Oil Packaging data are gathered from TÜİK database; the data period is annual but in fiscal calendar years. Inflow and outflow of Packaging, bulk olive oil production amount and olive oil consumption amount are published by IOC; their

Table 7.3: Processing Variables - Parameter Setting

Converter	Reference
Processed Bulk Food Inventory (t_0) = 30,000 (Kg)	Calibrated
Bulk Food Export Time = 1 (Months)	Assumed
Bulk Food Demand Averaging Time = 12 (Months)	Assumed
Bulk Food Supply Averaging Time = 12 (Months)	Assumed
Processing Time = 3 (Months)	Assumed
Processing Yield = Historical Graphical Data	TÜİK & IOC
Reference Process Utilization = 1 (Dimensionless)	Assumed
Sensitivity of Process Utilization to Profitability = 0.10 (Dimensionless)	Assumed

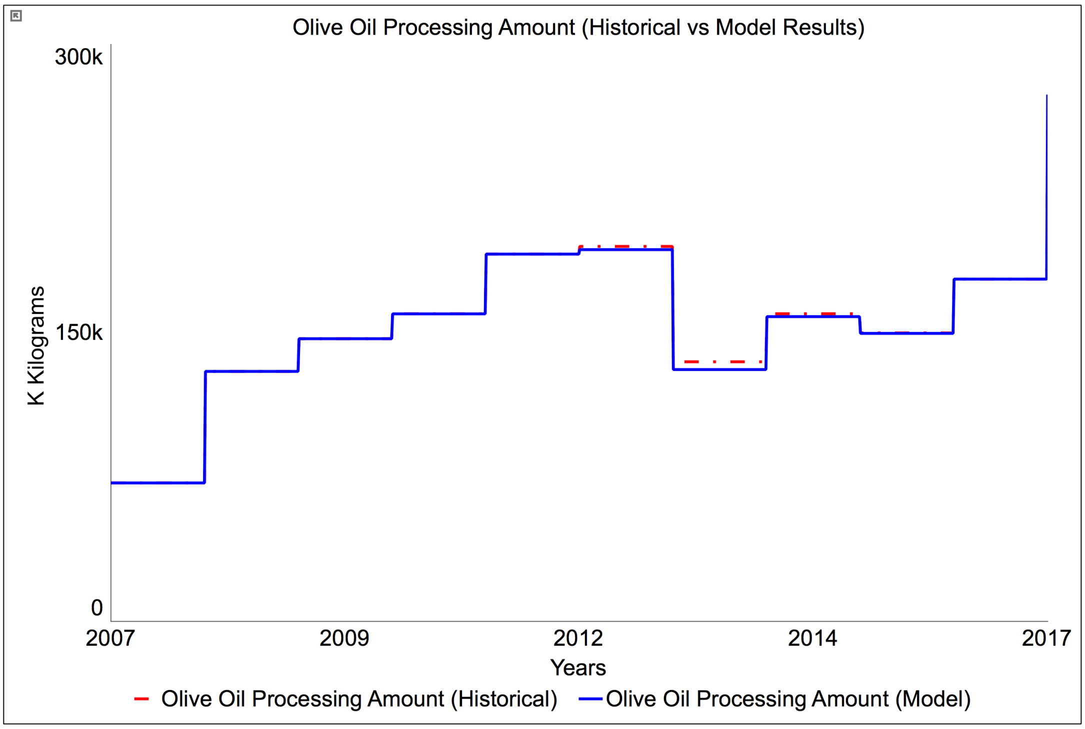

Figure 7.7: Historical Values and Model Results for Olive Oil Processing (2007-2017)

data periods are annual but in harvest years (from October to September). Initial runs with these data sets arise some questions about the "confirmity of physical laws" among these data sets, i.e., do Bulk Olive Oil Inventory and Packaged Olive Oil Inventory Levels stay non-negative in order to reproduce the amounts in the data sets mathematically? In order to inquire this question, we build simple Conservation Law Control Models.

- **Aggregate Conservation Law Control Model:** This simple model is to check the conformity of conservation law in the case of inflow of annual bulk olive oil processing and outflow of annual olive oil consumption with the annual export rate. For the stock and flow diagram of the model, see Figure 7.8. The time unit of this model is Years and delta time step is $dt = 1/8$. The run results of this model confirm to the physical law of conservation, and as the output, its gives us the "End of Year Inventory Levels" in order to confirm the flow of these data sets (Figure 7.9). These inventory levels are used as reference levels in the following steps.

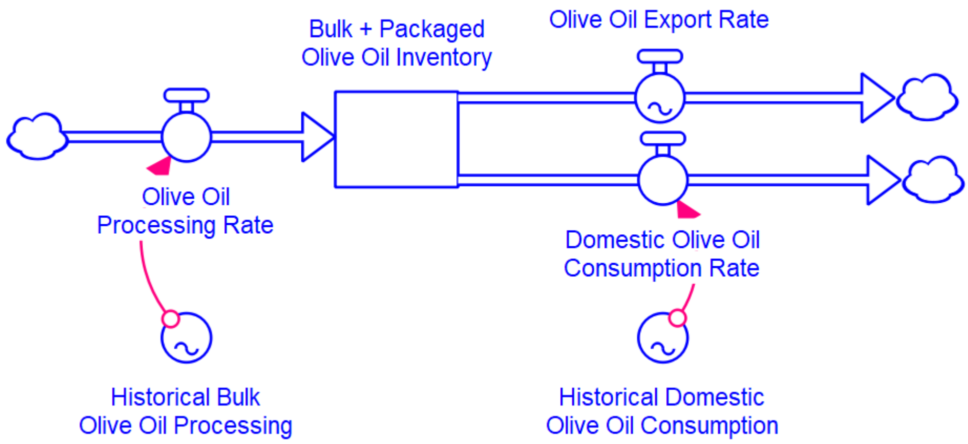

Figure 7.8: Stock and Flow Diagram of Aggregate Conservation Law Control Model

- Conservation Law Control Model with Packaging: In this step, olive oil inventories and olive oil export are separated as Bulk Olive Oil and Packaged Olive Oil, and Packaging operation flow is added to the model. For the stock and flow diagram of the model, see Figure 7.10. For the initial runs, the annual data published by TÜİK are used and it is observed that physical conservation law in

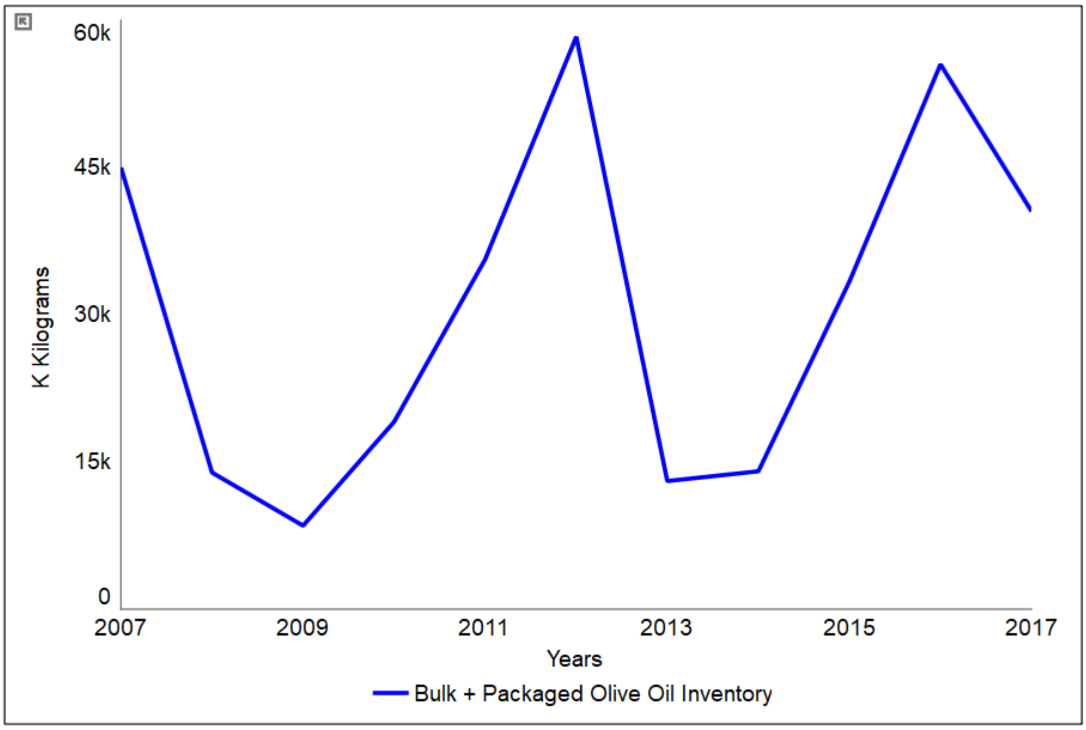

Figure 7.9: Total Bulk + Packaged Olive Oil Inventory Levels as a Result of Aggregate Conservation Law Control Model

inventories does not hold. Hence, we add “Packaging Correction Coefficient” to the model and state the optimization problem as: “In order to satisfy historical processing, historical consumption, historical exports and End of Year Inventory Levels determined in Aggregate Conservation Law Control Model, what are the optimal values of Packaging Correction Coefficients along time?” where:

Olive Oil Packaging Rate = Historical Olive Oil Packaging * Packaging Correction Coefficient.

As the solution of the optimization problem, we obtain how much deviation exists between a feasible packaging flow data set and reported packaging data by TÜİK (see Figure 7.11.) Then we rename the new data set as “Corrected Packaging Amount” and the calibration in the following steps are conducted according to the corrected values.

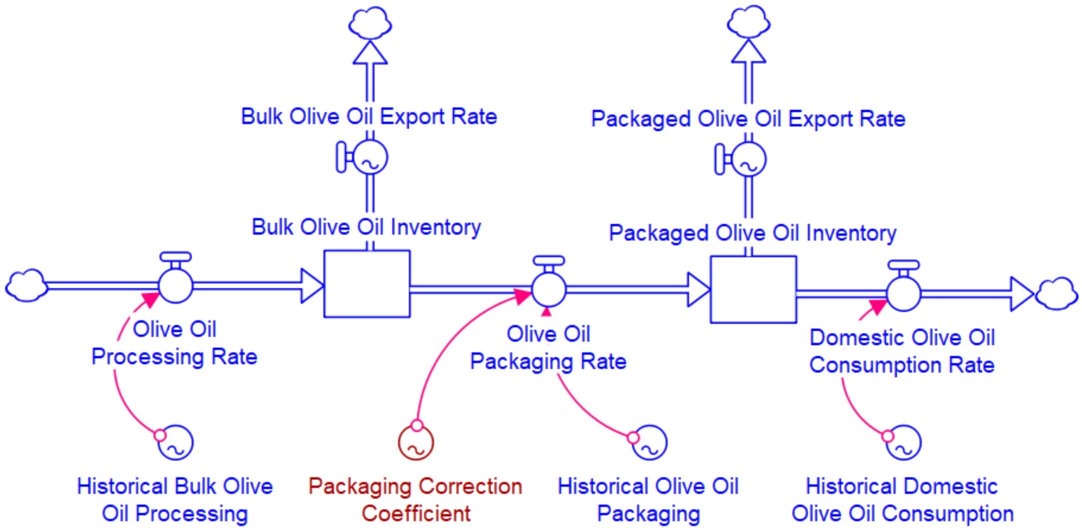

Figure 7.10: Stock and Flow Diagram of Conservation Law Control Model with Packaging

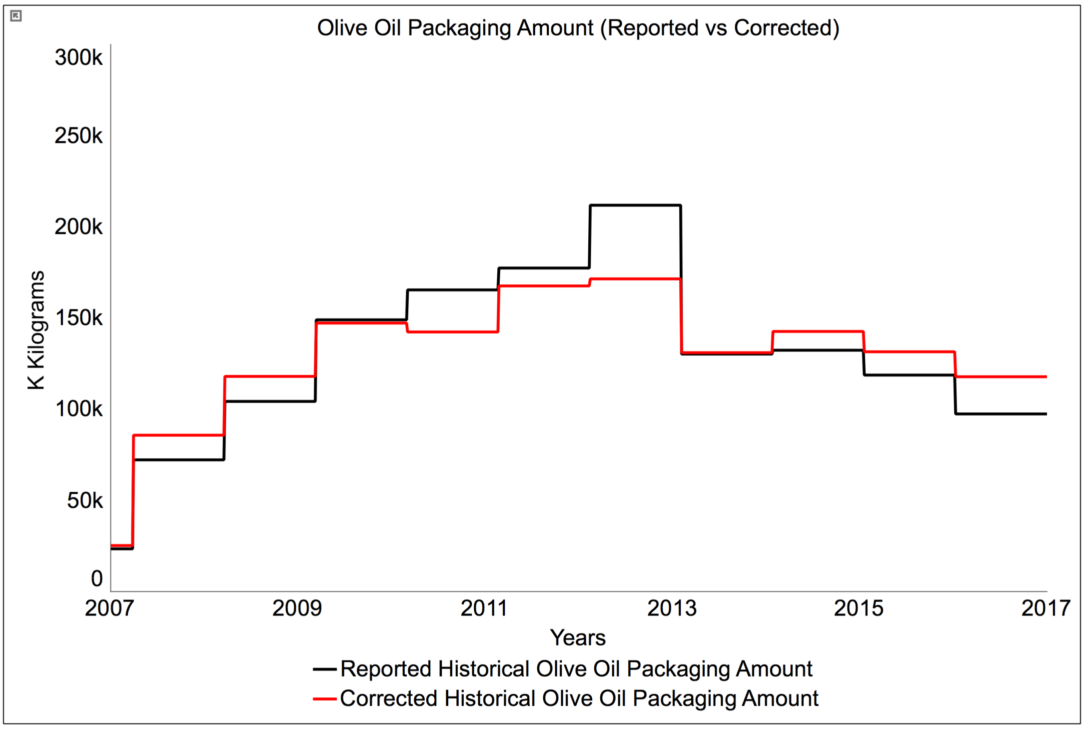

Figure 7.11: Reported and Corrected Annual Olive Oil Packaging Levels

7.5.2 Model Structure Improvements for Application

In application of Olive Oil Packaging module, only one structural improvement is made: formulation of Desired Packaging Rate is improved with Effect of Processing Volume on Packaging Rate. With this improvement, Reference Packaging Rate is defined as a constant value. The modifications are as follows:

Desired Packaging Rate = SMTH1(Reference Packaging Rate*Effect of Profitability on Packaging Rate*Effect of Processing Volume on Packaging Rate, Desired Packaging Rate Adjustment Time)

Effect of Processing Volume on Packaging Rate = SMTH1((Total Bulk Food/Reference Processing Volume for Packaging Rate) ^ Sensitivity of Packaging Rate to Processing Volume, Processing Volume Effect Adjustment Time)

Reference Packaging Rate = Constant.

Reference Processing Volume for Packaging Rate = Constant.

7.5.3 Parameter Setting and Module Calibration

- Initial value of Packaged Food Inventory is calibrated simultaneously with initial Processed Bulk Food Inventory during the conservation law control procedure and set to 15,000 Kg.

- Desired Packaging Rate Adjustment Time is assumed to be 1 Month.

- Operation times are expected to be short compared to other delay or adjustment times within the model. Distribution and Retailing Time and Packaging Time are assumed to be 0.5 Months each and Packaged Food Export Time is assumed to be 1 Month.

- Maximum Utilization is set to 1 depending on its definition.

- Sensitivity of Packaging Rate to Profitability is known to be slightly effective and assumed to be 0.10.

- Reference Packaging Rate, Reference Processing Volume for Packaging, Processing Volume Effect Adjustment Time and Sensitivity of Packaging Rate to Processing Volume are determined simultaneously as the solution of the minimization problem for which the objective function is the "sum of square errors between the annual olive oil packaging amount generated by the model and the corrected historical data of olive oil packaging amount" plus "sum of errors between the end of the year inventories of olive oil generated by the model and corrected historical data on the end of the year inventories of olive oil, raised to the power of four". The details of the calibration problem are given below.

Calibration Problem for Olive Oil Packaging:

Minimize
$\sum \left(\text{Annual Packaging Amount}_M - \text{Annual Packaging Amount}_{H,C}\right)^2$
$+ \sum \left(\text{End of Year Olive Oil Inventory}_M - \text{End of Year Olive Oil Inventory}_{H,C}\right)^4$
subject to

$$10{,}000 \leq \text{Reference Packaging Rate} \leq 40{,}000$$
$$100{,}000 \leq \text{Reference Processing Volume for Packaging} \leq 200{,}000$$
$$1 \leq \text{Processing Volume Effect Adjustment Time} \leq 15$$
$$0.1 \leq \text{Sensitivity of Packaging Rate to Processing Volume} \leq 0.9$$

Calibration Checklist for Olive Oil Packaging:

- **Statement and compatibility of Dynamic Hypothesis and Reference Mode:** Packaging Rate is affected by annual bulk food processing amount and the profitability of packaging operations.

- **Usage of all available knowledge about the system parameters:** Domestic consumption, export, packaging profitability and processing volume are used depending on their historical values.

- **Building the smallest possible calibration problem:** Since packaging rate and olive oil inventory level are directly related, yearly packaging amount and end of year olive oil inventory level are simultaneously calibrated. That is, we aim to minimize the error in yearly packaging amount and end of year olive oil inventory level via determining Reference Packaging Rate, Reference Processing Volume for Packaging, Processing Volume Effect Adjustment Time and Sensitivity of Packaging Rate to Processing Volume.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** Sensitivity of Packaging Rate to Processing Volume is larger than Sensitivity of Packaging Rate to Profitability as expected. Sensitivity of Packaging Rate to Profitability is set to a small value similar to other profitability oriented sensitivity values in other modules. Reference Packaging Rate is high enough to be consistent with the strong Effect of Processing Volume on Packaging Rate values. Reference Processing Volume for Packaging is closer to average of historical Processing Volume data. Processing Volume Effect Adjustment Time is long enough but shorter than a year, which is appropriate to change perceptions on Effect of Processing Volume on Packaging Rate.

- **Calibration of initial conditions:** Besides the calibration problem defined above, initial value of Packaged Food Inventory is calibrated simultaneously with initial Processed Bulk Food Inventory during the conservation law control procedure described above.

- **Searching for alternative structures:** Effect of Processing Volume on Packaging Rate is added to the model.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.4.

After the parameter setting, the resulting partial model test result for the Olive Oil Packaging Amount can be seen in Figure 7.12. MAPE between model generated results and historical values is 8.5%.

Table 7.4: Packaging Variables - Parameter Setting

Converter	Reference for Setting
Packaged Food Inventory (t_0) = 15,000 (Kg)	Calibrated
Desired Packaging Rate Adjustment Time = 1 (Months)	Assumed
Distribution and Retailing Time = 0.5 (Months)	Assumed
Packaging Time = 0.5 (Months)	Assumed
Maximum Utilization = 1 (Dimensionless)	Definitional
Packaged Food Export Time = 1 (Months)	Assumed
Processing Volume Effect Adjustment Time = 7.7 (Months)	Calibrated
Reference Packaging Rate = 12,409 (Kg/Month)	Calibrated
Reference Processing Volume for Packaging Rate = 159,736 (Kg)	Calibrated
Sensitivity of Packaging Rate to Processing Volume = 0.74 (Dimensionless)	Calibrated
Sensitivity of Packaging Rate to Profitability = 0.10 (Dimensionless)	Assumed

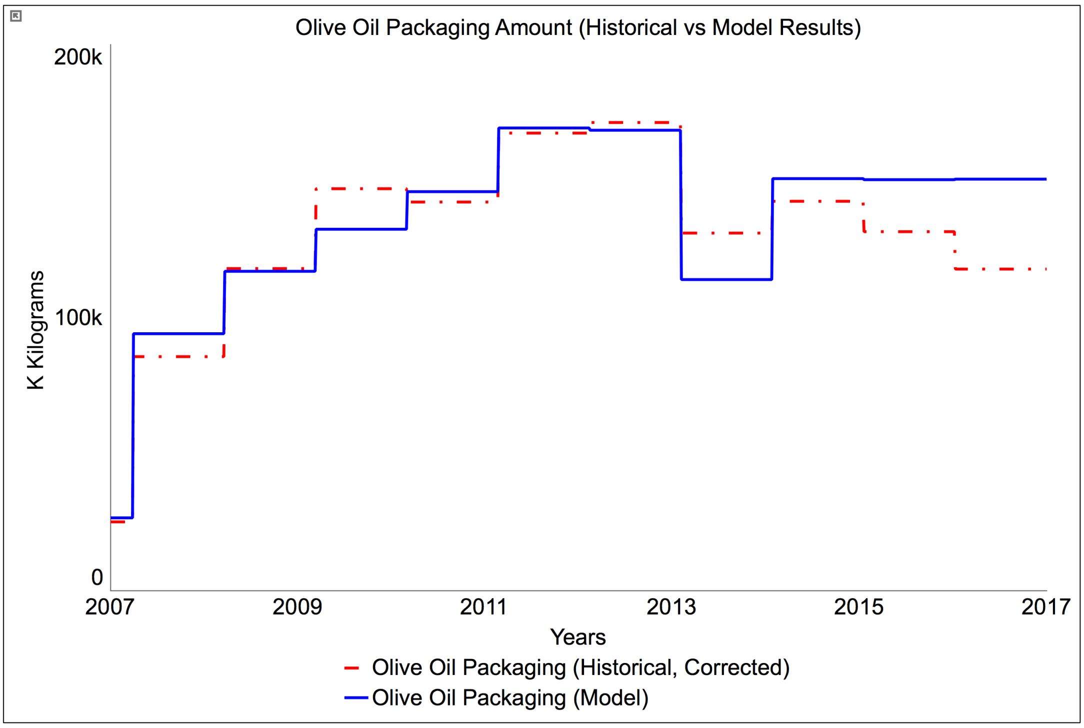

Figure 7.12: Historical Values and Model Results for Olive Oil Packaging (2007-2017)

7.6 Olive Oil Demand

7.6.1 Data Analysis and Implications

As an indicator of Olive Oil Demand in Turkey, we have only yearly data of olive oil consumption in Turkey. Different from many other data sets related to demand, such as Population or GDP, olive oil consumption data are not provided in fiscal calendar year but in agricultural harvest year (i.e. from October of one year to September of the next year.) With the harvest year viewpoint, dynamics of the corresponding data in Olive Oil Demand sector from 2007-2008 (labeled as 2007) to 2017-2018 (labeled as 2017) in Turkey can be found in Figure 7.13. The data are presented in two parts: the upper part of Figure 7.13 consists of available annual data, whereas lower part consists of available monthly data for the same period.

The observations gathered from these data sets are as follows:

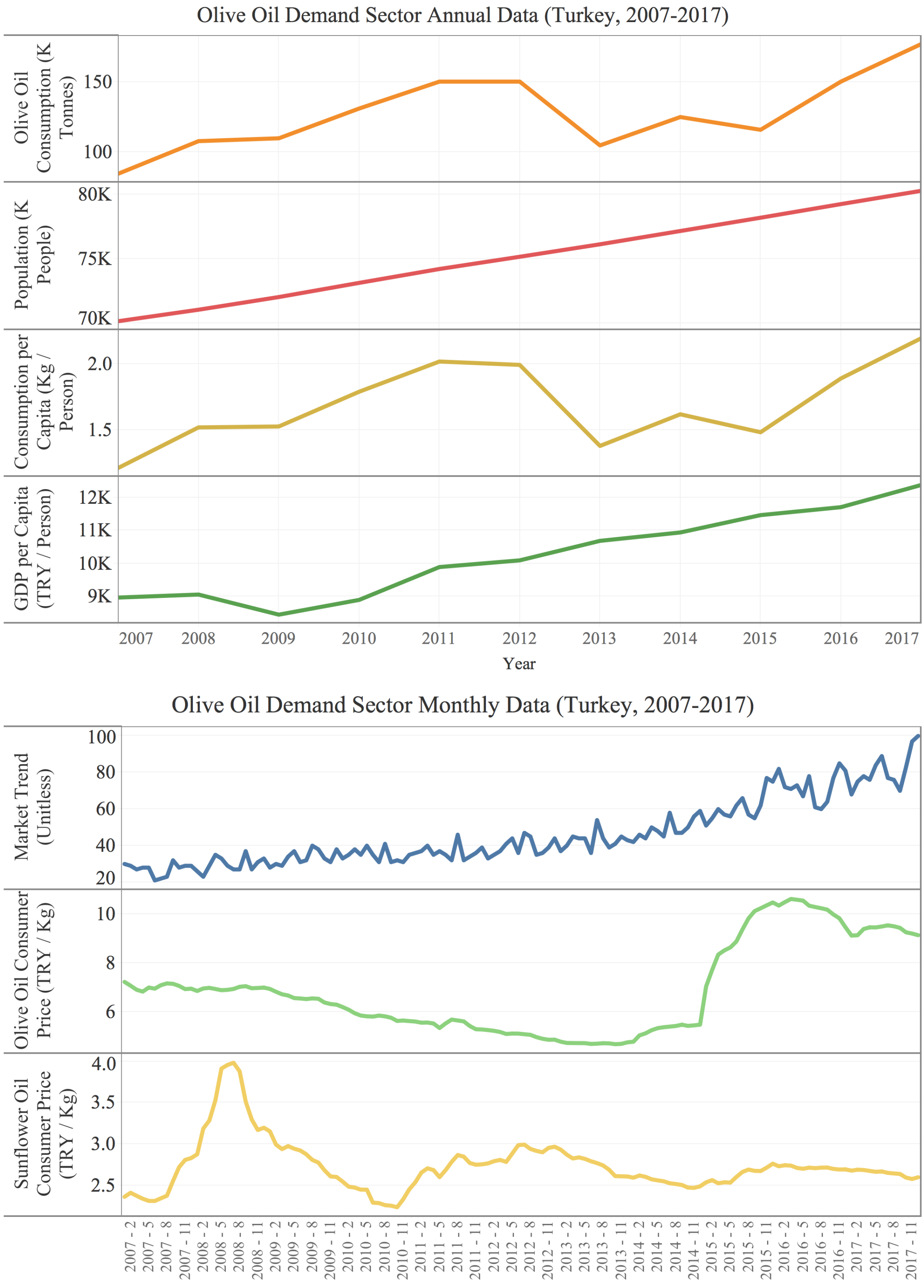

Figure 7.13: Olive Oil Demand Sector Annual and Monthly Data in Turkey, 2007-2017

- GDP, Population and Market Trend are showing an increasing trend. These trends are expected to create a growth in the consumption side.

- Olive Oil Consumption and Olive Oil Consumption per Capita do not show a stationary behavior. Their behavior is found to be correlated with the annual Olive Oil Processing amount (see Figure 7.6). This observation brings about the hypothesis that total consumption depends on total bulk olive oil, i.e. availability of olive oil at the national level.

- Sunflower oil consumer price shows a more stationary behavior in recent years, whereas olive oil consumer price shows a sharp increase.

7.6.2 Model Structure Improvements for Application

In application of Olive Oil Demand module, only one structural improvement is made: Indicated Demand per Capita is improved with Effect of Product Availability on Demand in order to reflect the effect of product volume to total consumption. The modified set of formulations are as follows:

Indicated Demand per Capita = Reference Demand per Capita * Effect of Consumer Price on Demand * Effect of Substitute Price on Demand * Effect of GDP on Demand * Effect of Market Trend on Demand * Effect of Product Availability on Demand.

Effect of Product Availability on Demand = (Total Bulk Food / Reference Product Availability)^Sensitivity of Demand to Product Availability.

Reference Product Availability = Constant.

Sensitivity of Demand to Product Availability = $0.1 \leq$ Constant ≤ 1.

7.6.3 Parameter Setting and Module Calibration

The parameter settings in Olive Oil Demand sector can be summarized as below:

- For the initial value of the Olive Oil Demand, the average monthly consumption of 2007-2008 harvest year is considered.
- Population, GDP per Capita, Market Trend and Substitute Price are directly gathered from their reference sources and embedded to the model as exogenous variables. Their values in time series can be seen in Figure 7.13. For their future values (values after December 2017), appropriate forecasting models based on their previous data are used.
- Demand Adjustment Time is determined through a set of analysis runs which are simultaneously conducted with the calibration procedure. It is observed that, in order to minimize the sum of square errors, demand should react to changes in its dependents quickly. Hence, Demand Adjustment Time is set as a small value, which is 0.5 Months.
- Maximum Consumption is determined as a large number which is high enough to be an upper bound on the monthly consumption rate.
- Maximum Effect of Retail Price, Minimum Effect of Market Trend and Minimum Effect of Substitute Price are set to appropriate large/small values which are only to be considered under extreme conditions.
- For the Reference Demand per Capita, the average monthly consumption of 2007-2008 harvest year is considered. For Reference GDP per Capita and Reference Market Trend, their corresponding values at the end of September 2007 (at the beginning of the October 2007) are used.
- Reference Substitute Price, Reference Retail Price, Reference Olive Oil Product Availability and sensitivity values in the module are determined as the solution of the calibration problem which minimizes "the sum of square errors between the annual olive oil quantity demanded as generated by the model and the historical data of annual olive oil consumption amount".

Calibration Problem for Demand Module:

Minimize

$\sum (\text{Annual Quantity Demanded}_M - \text{Annual Quantity Consumed}_H)^2$

subject to

$$70{,}000 \leq \text{Reference Olive Oil Product Availability} \leq 200{,}000$$
$$6 \leq \text{Reference Retail Price for Demand} \leq 9$$
$$2 \leq \text{Reference Substitute Price} \leq 3$$
$$-1.0 \leq \text{Sensitivity of Demand to Consumer Price} \leq -0.3$$
$$0.1 \leq \text{Sensitivity of Demand to Market Trend} \leq 0.3$$
$$0.1 \leq \text{Sensitivity of Demand to Product Availability} \leq 0.5$$
$$0.1 \leq \text{Sensitivity of Demand to Substitute Price} \leq 0.3$$

Calibration Checklist for Demand Module:

- **Statement and compatibility of Dynamic Hypothesis and Reference Mode:** The dynamic hypothesis on the Demand module is that quantity demanded is increasing with GDP, Market Trend, Substitute Product Price and Product Availability and decreasing with Retail Price. Among these determinants, only the effect of GDP is found to be smaller than expected, but for the sake of completeness and depending on the knowledge about the system, Effect of GDP is kept within the model but with a smaller sensitivity value.

- **Usage of all available knowledge about the system parameters:** Historical olive oil processing and packaging volume, historical retail price, historical GDP, historical substitute price, historical market demand and historical population are used during calibration.

- **Building the smallest possible calibration problem:** The smallest possible calibration problem is achieved by considering only annual demand and consumption values in the objective function and optimizing the selected sensitivity and reference values.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** As it is expected from the initial data analysis, Sensitivity of Demand to Product Availability is found to be the highest and Sensitivity of Demand to GDP per Capita is found to be the lowest among all sensitivity values. Sensitivity of Demand to Consumer Price is the second highest one, which is also expected. Sensitivity of Demand to Market Trend and Sensitivity of Demand to Substitute Price have closer values and less than Sensitivity of Demand to Consumer Price.

- **Calibration of initial conditions:** Initial condition for quantity is not required to be calibrated, since historical data is used in 2007-2008 season. Yet, reference values of selected effect functions are calibrated.

- **Searching for alternative structures:** Effect of Product Availability on Demand is added to the model.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.5.

After setting the parameters, the resulting partial model test result for Olive Oil Demand Module can be seen in Figure 7.14. MAPE between historical data of Olive Oil Consumption and model generated Olive Oil Demand is found to be 5.8%.

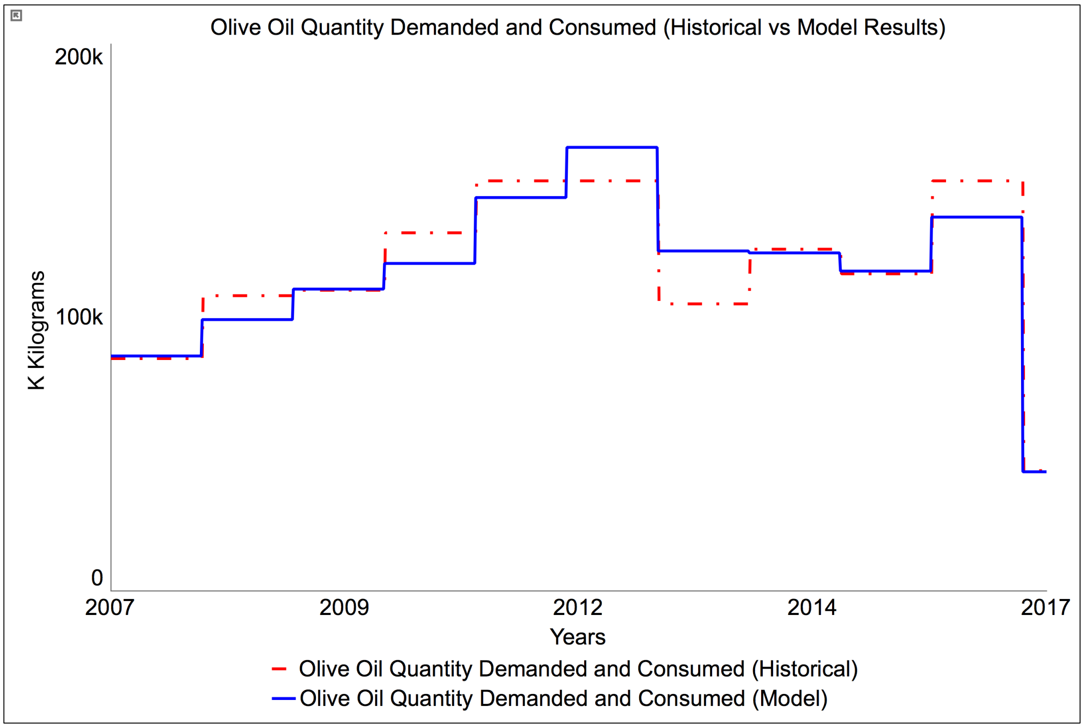

Figure 7.14: Historical Values and Model Results for Olive Oil Consumption and Demand, 2007-2017

Table 7.5: Demand Variables - Parameter Setting

Converter	**Reference**
Olive Oil Demand (t_0) = 7083.3 (K Kg/Month)	IOC
Population = Historical Graphical Data (K People)	TÜİK
GDP per Capita = Historical Graphical Data (TRY/Person)	TÜİK
Market Trend = Historical Graphical Data (Dimensionless)	Google Trends
Substitute Price = Historical Graphical Data (TRY / Kg)	TÜİK
Demand Adjustment Time = 0.5 (Months)	Assumed
Maximum Consumption = 32,000 (K Kg/Month)	Assumed
Maximum Effect of Retail Price = 10 (Dimensionless)	Assumed
Minimum Effect of Market Trend = 0.1 (Dimensionless)	Assumed
Minimum Effect of Substitute Price = 0.1 (Dimensionless)	Assumed
Reference Demand per Capita = 0.101 (Kg/Month/Person)	IOC
Reference GDP per Capita = 8,962 (TRY/Person)	TÜİK
Reference Market Trend = 32 (Dimensionless)	Google Trends
Reference Substitute Price = 2.78 (TRY/Kg)	TÜİK
Reference Olive Oil Product Availability = 110,330 (K Tons)	Calibrated
Reference Retail Price for Demand = 7.92 (TRY/Lt)	Calibrated
Sensitivity of Demand to Consumer Price = -0.30 (Dimensionless)	Calibrated
Sensitivity of Demand to GDP per Capita = 0.05 (Dimensionless)	Assumed
Sensitivity of Demand to Market Trend = 0.113 (Dimensionless)	Calibrated
Sensitivity of Demand to Product Availability = 0.50 (Dimensionless)	Calibrated
Sensitivity of Demand to Substitute Price = 0.105 (Dimensionless)	Calibrated

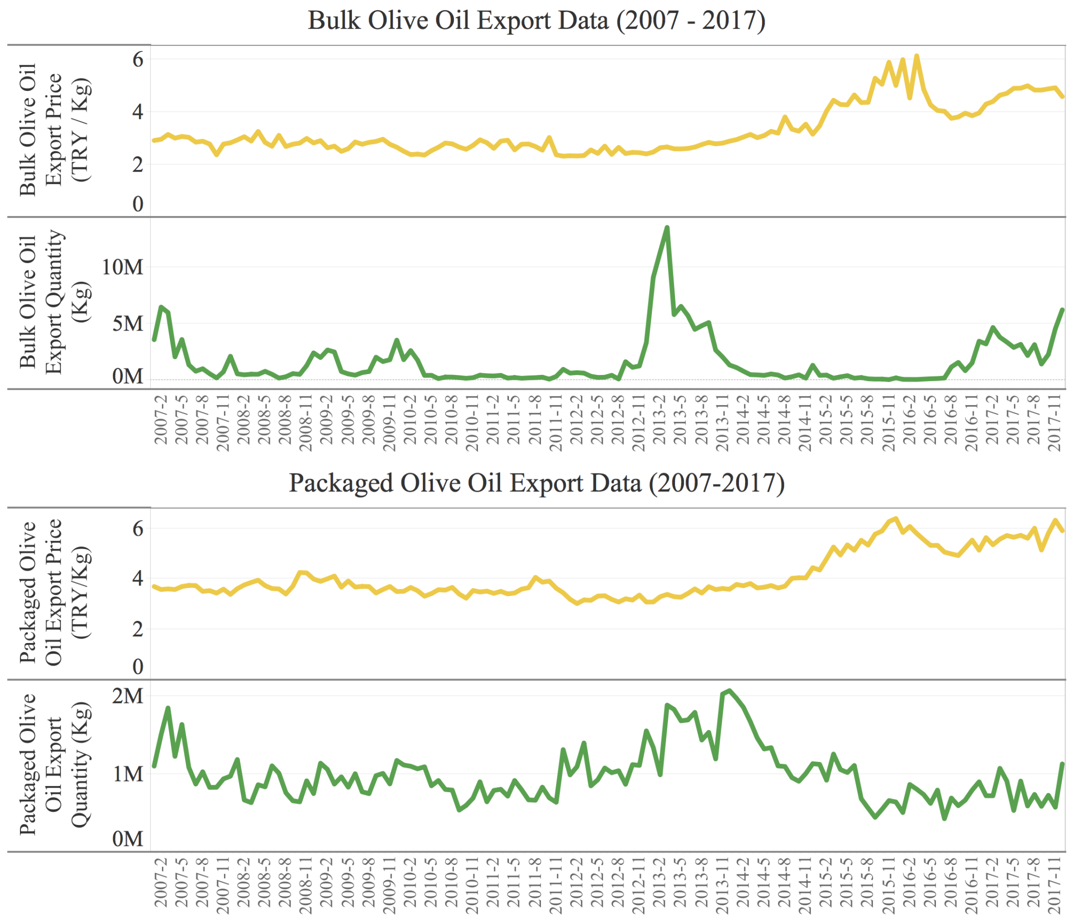

Figure 7.15: Olive Oil Export Sector Data in Turkey, 2007-2017

7.7 Olive Oil Export

In Olive Oil Export module, data on export quantities and export prices are used exogenously and gathered from TÜİK database as their historical occurrences. Their statistics between 2007-2017 can be seen in Figure 7.15. Unit export prices are in increasing trend, whereas export quantities are fluctuating and for some data points they show abrupt changes (see the end of 2012 and beginning of 2013 in Bulk Olive Oil Export Quantity Graph.) We know that Turkey is a price taker, not a price maker, in the world olive oil market and the export quantities are mainly based on the situation in world supply and demand. Hence, their historical occurrences are used as exogenous variables in the model. For their future values, appropriate forecasting models based on their historical data are used.

7.8 Fruit Price Setting

7.8.1 Data Analysis and Implications

In price setting stages, the most important components are costs and financial subsidies. Before investigating the data in Figure 7.16, we should explain the structure of Fixed Cost of Growing, Variable Cost of Harvesting and Financial Aid for Olive Growing.

Unfortunately, we do not have data sources for annually changing levels of Fixed Cost of Growing and Variable Cost of Harvesting. Yet, we have only official data for one point of 2015-2016 harvest year published by IOC. By using this data point and appropriate indicators for change, we make projections for the time horizon of the model. The details of these projections and calculations are given below.

Fixed Cost of Growing: Fixed Cost of Growing consists of fertilization, plant protection, soil management and pruning. According to olive oil production cost study by IOC (2015), these activities cost 90, 36, 113 and 116 Euros per hectare in Turkey, respectively. When this study is conducted, our olive cultivated area is reported as 798,493 hectares, and total olives harvested is 1,700,000 tonnes. As the reference date of this study, October 2015 is taken when the harvest starts for 2015-2016 harvest year, and in October 2015, 1 Euro is 3.20 TRY. Hence, the unit fixed cost of growing is calculated as (90+36+113+116)*3.20/(1,700,000,000/798,493) = 0.534 TRY in October 2015's costs. Since the model always works with 2003 = 100 real costs, this value is converted to 2003 = 100, which is 0.534/(253.74/100) = 0.210 TRY/Kg.

Variable Cost of Harvesting: Variable Costs of Harvesting consist of mainly unit labor costs and unit machinery costs (if any) regarding fruit collection. In a similar way to Fixed Cost of Growing, Variable Cost of Harvesting is 348 Euros per hectare in Turkey depending on IOC (2015). Then, Variable Harvesting Cost is calculated as 348*3.20/(1,700,000,000/798,493) = 0.523 TRY/Kg in October 2015's cost which is 0.523/(253.74/100) = 0.206 TRY/Kg in 2003 = 100.

For the projections of Fixed Cost of Growing throughout the time horizon of the model, weighted averages of changes in real values of labor cost of hoeing / pruning, fertilizer prices and diesel prices are used. For the projections of Variable Cost of Harvesting, changes in real values of labor cost of harvesting is used.

Financial Aid for Olive Growing: In the generic model, the name of the financial aid given at that stage was Financial Aid for Harvesting. Yet, in Turkey, financial aid at that stage is given for the activities only related to fixed cost. Hence, the name of the variable is redefined as Financial Aid for Olive Growing. In Turkey, the financial subsidies given in that stage consist of subsidies for fertilizers and subsidies for diesel. These subsidies are given depending on the size of the cultivation area. In order to use these values in the model, they are converted to real TRY/Kg values.

The real values of unit costs, financial aids and unit prices can be seen in Figure 7.16.

The significant observations gathered from 7.16 can be summarized as follows:

- Olives for Oil Harvest Amount and Variable Cost of Harvesting are in increasing trend.
- Fixed Cost of Growing is subject to slight fluctuations whereas Financial Aid for Olive Growing is stable except the first year of the time horizon.
- Depending on the observation of data patterns, olive fruit price seems to be affected by olives for oil harvest amount significantly and by costs and financial aids moderately.

7.8.2 Model Structure Improvements for Application

In application of Olive Fruit Price Setting module, a set of structural improvements and modifications are done. They can be explained as follows:

- Effect of Mature Trees on Fixed Cost of Growing is added to the model. In the generic model, unit fixed cost of growing and harvesting operations is independent of capacity, i.e. stock of mature trees. In order to reflect the "economies of scale" to the fixed costs, Effect of Mature Trees on Fixed Cost of Growing is defined in the way that Fixed Cost of Growing is decreasing with Mature Trees. The mathematical formulations are modified as below:

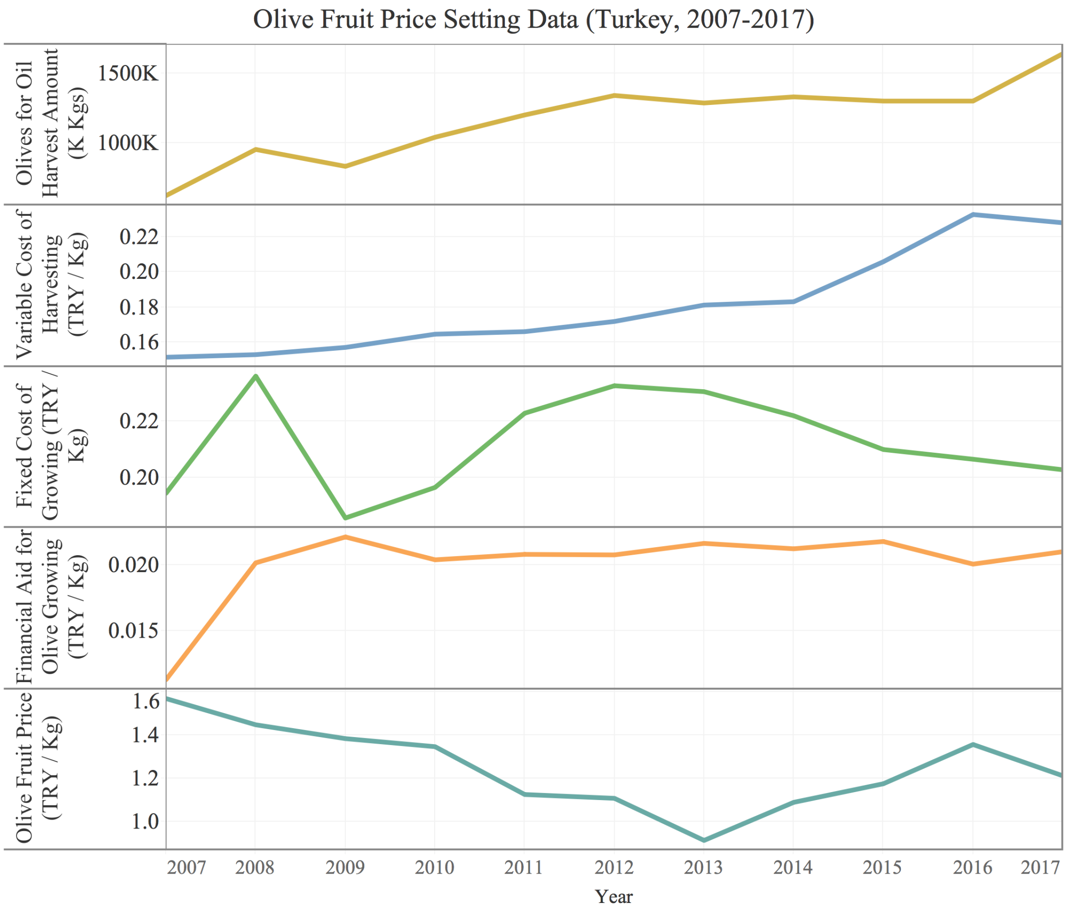

Figure 7.16: Olive Fruit Price Setting Data in Turkey, 2007-2017

Fixed Cost of Growing = Reference Fixed Cost of Growing * Effect of Mature Trees on Fixed Cost of Growing

Reference Fixed Cost of Growing = Graphical Historical Data.

Effect of Mature Trees on Fixed Cost of Growing = (Mature Trees/Reference Mature Trees)^Sensitivity of Fixed Cost to Mature Trees.

Reference Mature Trees = Constant.

Sensitivity of Fixed Cost to Mature Trees = Constant.

- Effect of Profitability of Processing on Fruit Price is added to the model as a determinant of Fruit Price. In the generic case, Effect of Bulk Food Price on Fruit Price is already in the model to reflect the changes in Bulk Food Price level to Fruit Price. Yet, the investigation of real world data and the results of validity tests reveal the requirement of Effect of Profitability of Processing on Fruit Price. Consider the case of a financial improvement in variable costs of processing: in this case, Bulk Food Price is expected to decrease whereas its profitability may increase. Hence, Effect of Profitability of Processing on Fruit Price is required to be separated from the Effect of Bulk Food Price on Fruit Price. The modified formulations are given below:

  Fruit Price = Expected Fruit Price * Effect of Growing and Harvesting Costs on Fruit Price * Effect of Harvest on Fruit Price * Effect of Bulk Food Price on Fruit Price * Effect of Profitability of Processing on Fruit Price

  Effect of Profitability of Processing on Fruit Price =(Expected Profitability of Processing / Reference Profitability of Processing)^Sensitivity of Fruit Price to Profitability of Processing

  Sensitivity of Fruit Price to Profitability of Processing = Constant.

- Instead of one single Expected Fruit Price Adjustment Time, an asymmetric adjustment structure is built for Expected Fruit Price. The adjustment time is split into two components: Expected Fruit Price Adjustment Time Up and Expected Fruit Price Adjustment Time Down, either of which is active in the adjustment process depending on the direction of adjustment. The modified formulations are as follows:

Rate of Change in Expected Fruit Price =
IF Indicated Fruit Price - Expected Fruit Price > 0 THEN
(Indicated Fruit Price - Expected Fruit Price) / Expected Fruit Price Adjustment Time Up ELSE
(Indicated Fruit Price - Expected Fruit Price) / Expected Fruit Price Adjustment Time Down.

Expected Fruit Price Adjustment Time Up = Constant.

Expected Fruit Price Adjustment Time Down = Constant.

7.8.3 Parameter Setting and Module Calibration

The parameter settings in Olive Oil Fruit Price Setting module can be summarized as below:

- For the initial value of Expected Olive Fruit Price, historical value of Olive Fruit Price in September 2007 is used.
- Reference Fixed Cost of Growing, Variable Cost of Harvesting and Financial Aid for Growing are calculated with the data given in their reference sources as explained in Section 7.8.1 and embedded to the model as exogenous variables. Their values in time series can be seen in Figure 7.16. For their future values, appropriate forecasting models based on their historical data are used.
- Reference Fruit Price for Planting is calibrated during the calibration problem of Olive Tree Planting Module.
- Reference Mature Trees is set to historical data for trees in 2015-2016 harvest season, since the Reference Fixed Cost of Growing is normalized for that harvest year.
- Reference Profitability of Harvesting Adjustment Time is set to 12 Months and Perceived Bulk Food Price Adjustment Time is set to 0.5 Months. It is assumed that perceptions on reference profitability is adjusted in approximately one year whereas perception on market price level of bulk food is adjusted in a very short time.

- Expected Fruit Price Adjustment Time Up, Expected Fruit Price Adjustment Time Down, Reference Harvest Amount, Sensitivity of Fruit Price to Bulk Food Price, Sensitivity of Fruit Price to Harvest Amount, Sensitivity of Fruit Price to Growing and Harvesting Costs, Sensitivity of Fruit Price to Profitability of Processing and Sensitivity of Fixed Cost to Mature Trees are determined as the solution of the calibration problem which minimizes "the sum of squared errors between the monthly olive fruit price generated by the model and the historical data of monthly olive fruit price". The details of the calibration problem is given below.

Calibration Problem for Fruit Price Setting Module:

Minimize
$\sum (\text{Monthly Olive Fruit Price}_M - \text{Monthly Olive Fruit Price}_H)^2$
subject to

$$1 \leq \text{Expected Fruit Price Adjustment Time Up} \leq 15$$
$$1 \leq \text{Expected Fruit Price Adjustment Time Down} \leq 15$$
$$1{,}000{,}000 \leq \text{Reference Harvest Amount} \leq 2{,}000{,}000$$
$$0.1 \leq \text{Sensitivity of Fruit Price to Bulk Food Price} \leq 0.9$$
$$-0.9 \leq \text{Sensitivity of Fruit Price to Harvest Amount} \leq -0.1$$
$$0.1 \leq \text{Sensitivity of Fruit Price to Growing and Harvesting Costs} \leq 0.9$$
$$0.1 \leq \text{Sensitivity of Fruit Price to Profitability of Processing} \leq 0.9$$
$$-0.5 \leq \text{Sensitivity of Fixed Cost to Mature Trees} \leq -0.1$$

Calibration Checklist for Fruit Price Setting Module:

- **Statement and Compatibility of Dynamic Hypothesis and Reference Mode:** Olive Fruit Price is expected to be affected by Harvesting and Growing Costs and Harvest Volume as an indicator of availability or supply/demand ratio. Additionally, Olive Fruit Price is affected by Bulk Food Price level and profitability generated by Bulk Food Price, which is Profitability of Processing operations.

- **Usage of all available knowledge about the system parameters:** During fruit price module calibration, historical variable and fixed costs, historical financial aids, historical harvest amount and historical bulk food price are utilized.

- **Building the smallest possible calibration problem:** The smallest possible calibration problem is achieved by considering monthly error in olive fruit prices.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** Expected Fruit Price Adjustment Times are expected to be longer than adjustment times of other prices, which are found to be as expected as the result of the automated calibration. Magnitude of sensitivity values in the module are consistent with each other: Sensitivity of Fruit Price to Bulk Food Price is the highest whereas Sensitivity of Fruit Price to Profitability of Processing is the lowest.

- **Calibration of initial conditions:** Initial condition of Expected Fruit Price is not required to be calibrated, since historical value of Olive Fruit Price in September 2007 is used. Yet, Reference Harvest Amount is calibrated within the calibration problem described above.

- **Searching for alternative structures:** As alternative structures, Effect of Profitability of Processing on Fruit Price and Effect of Mature Trees on Fixed Cost of Growing are added to the model. Additionally, in order to build the asymmetric adjustment structure for Expected Fruit Price, adjustment time is split into two components as Expected Fruit Price Adjustment Time Up and Expected Fruit Price Adjustment Time Down.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.6.

After setting the parameters, the resulting partial model test result for Olive Fruit Price can be seen in Figure 7.17. MAPE between model generated results and historical values is 7.9%.

Table 7.6: Fruit Price Setting Variables - Parameter Setting

Converter	**Reference**
Expected Fruit Price (t_0) = 1.602 (TRY/Kg)	TÜİK
Reference Fixed Cost of Growing = Historical Graphical Data (TRY/Kg)	IOC & TÜİK
Variable Cost of Harvesting = Historical Graphical Data (TRY/Kg)	IOC & TÜİK
Financial Aid for Growing = Historical Graphical Data (TRY/Kg)	MAF
Expected Fruit Price Adjustment Time Up = 3.42 (Months)	Calibrated
Expected Fruit Price Adjustment Time Down = 15.0 (Months)	Calibrated
Reference Fruit Price for Planting = 0.942 (TRY/Kg)	Calibrated
Reference Harvest Amount = 1,014,243 K (Kg)	Calibrated
Reference Mature Trees = 144,760 (Each)	TÜİK
Reference Profitability of Harvesting Adjustment Time = 12 (Months)	Assumed
Perceived Bulk Food Price Adjustment Time = 0.5 (Months)	Assumed
Sensitivity of Fruit Price to Profitability of Processing = 0.1 (Dimensionless)	Calibrated
Sensitivity of Fruit Price to Bulk Food Price = 0.671 (Dimensionless)	Calibrated
Sensitivity of Fruit Price to Harvest Amount = -0.361 (Dimensionless)	Calibrated
Sensitivity of Fruit Price to Harvesting Costs = 0.286 (Dimensionless)	Calibrated
Sensitivity of Fixed Cost to Mature Trees = -0.500 (Dimensionless)	Calibrated

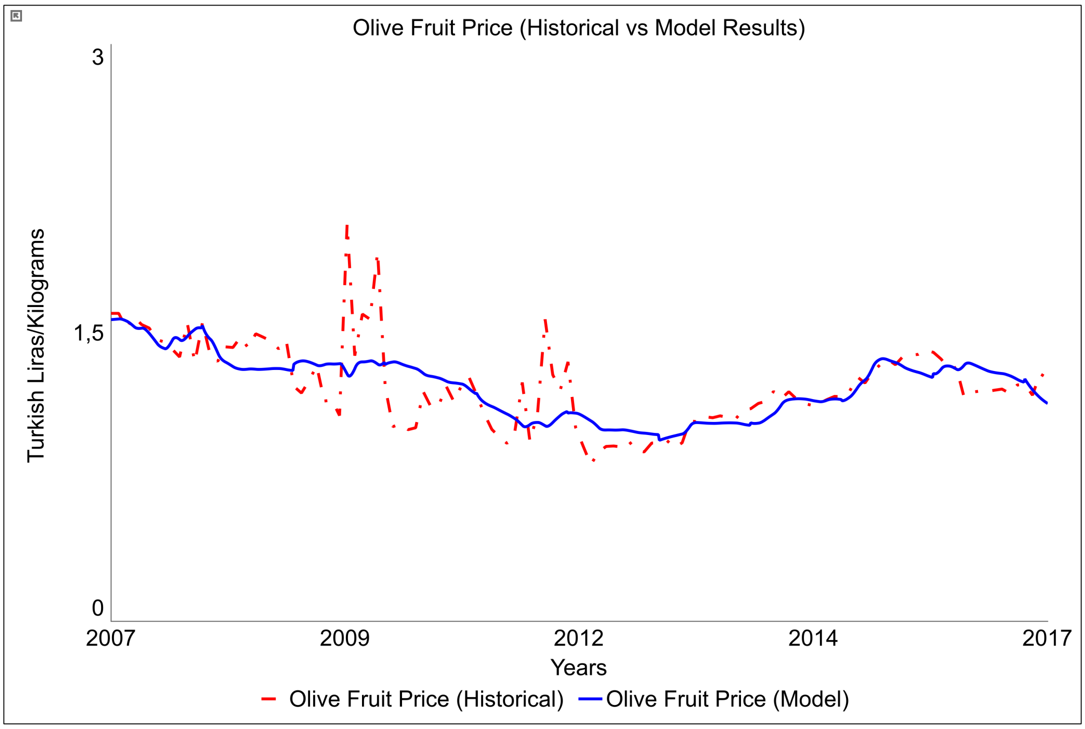

Figure 7.17: Historical Values and Model Results for Olive Fruit Price, 2007-2017

7.9 Bulk Food Price Setting

7.9.1 Data Analysis and Implications

Similar to Fruit Price Setting module, we experience several issues about the data availability on olive oil processing costs over the time horizon of the model. Hence, we use the official data for one point of 2015-2016 harvest year published by IOC with appropriate indicators to make projections about the behavior of costs. Before investigating the behaviors in Figure 7.18, we should explain the structure of Variable and Fixed Cost of Processing.

Variable and Fixed Cost of Processing: According to IOC cost study, unit variable processing cost is 0.076 Euros/Kg in October 2015. Then, in TRY values, unit variable processing cost is 0.076*3.20 = 0.2432 TRY / Kg. According to another study conducted on olive oil value chain formation in Spain (The Olive Oil Agency, 2010), variable cost covers 23% and fixed cost covers 77% of processing cost. Then, unit

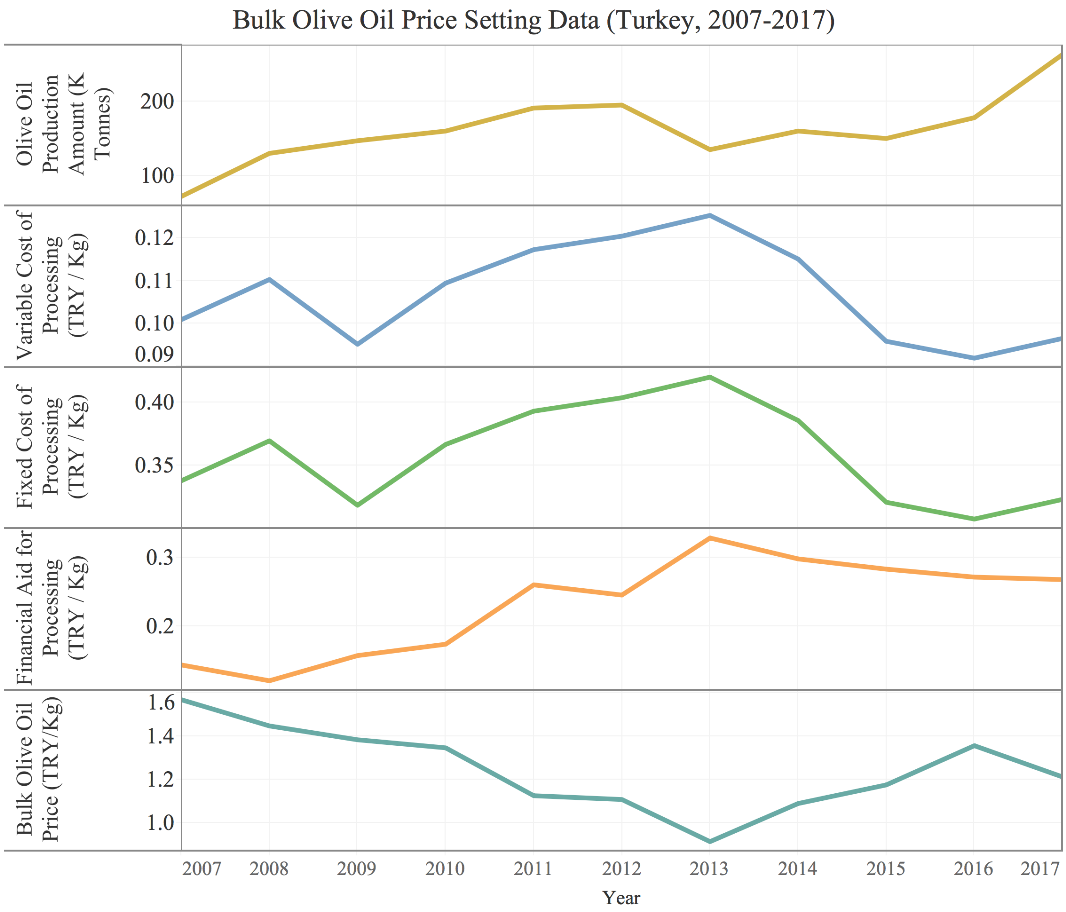

Figure 7.18: Bulk Olive Oil Price Setting Data in Turkey, 2007-2017

Fixed Cost of Processing is calculated as 0.8142 TRY / Kg. Since we always work with real values according to 2003 = 100 index, we convert variable and fixed cost of processing to 2003 = 100, which are 0.2432/(253.74/100) = 0.0958 TRY / Kg and 0.8142/(253.74/100) = 0.3208 TRY / Kg, respectively.

For the projections of Variable and Fixed Cost of Processing throughout the time horizon of the model, changes in real values of diesel prices are utilized.

The significant observations gathered from Figure 7.18 can be summarized as follows:

- Olive Oil Production Amount is in increasing trend.
- Variable Cost of Processing and Fixed Cost of Processing do not show a trend but show slight fluctuations.

- Bulk Olive Oil Price and Financial Aid of Processing show a strong negative relationship.

7.9.2 Model Structure Improvements for Application

In application of Bulk Olive Oil Price Setting module, a set of structural improvements and modifications are done. They can be explained as follows:

- Similar to the structure added in Fruit Price Setting module, Effect of Harvest Volume on Fixed Cost of Processing is added to the model. In the generic model, unit cost of processing operations remains constant in changing input amount, i.e. olive fruit harvest amount. In order to reflect the idea of "economies of scale" as done in Fruit Price Setting module, Effect of Harvest Volume on Fixed Cost of Processing is defined in the way that Fixed Cost of Processing is decreasing in Harvest Amount. The mathematical formulations are modified as below:

  Fixed Cost of Processing = Reference Fixed Cost of Processing * Effect of Harvest Volume on Fixed Cost

  Reference Fixed Cost of Processing = Graphical Historical Data.

  Effect of Harvest Volume on Fixed Cost = (Harvest Amount / Reference Harvest Volume for Fixed Cost) ^ Sensitivity of Fixed Cost to Harvest Volume

  Reference Harvest Volume for Fixed Cost = Constant.

  Sensitivity of Fixed Cost to Harvest Volume = Constant.

- Effect of Packaging Profitability on Bulk Food Price is added to the model as a determinant of Bulk Food Price. The reasoning of this modification is the same as in Fruit Price Setting: to differentiate the effects of changing price levels and profitability. The modified formulations are given below:

  Bulk Food Price = Expected Bulk Food Price * Effect of Processing Costs on Bulk Food Price * Effect of Supply Demand Ratio on Bulk Food Price * Effect of Export Price on Bulk Food Price * Effect of Retail Price on Bulk Food Price * Effect of Packaging Profitability on Bulk Food Price

Effect of Packaging Profitability on Bulk Food Price = (Expected Profitability of Packaging/Reference Profitability of Packaging) ^ Sensitivity of Bulk Food Price to Packaging Profitability

Sensitivity of Bulk Food Price to Packaging Profitability = Constant.

- The asymmetric adjustment structure is built for Expected Bulk Food Price, as in Fruit Price Setting module. The adjustment time is split into two components: Expected Bulk Food Price Adjustment Time Up and Expected Bulk Food Price Adjustment Time Down only, either of which is active in adjustment process depending on the direction of adjustment. The modified formulations are as follows:

  Rate of Change in Expected Bulk Food Price =
  IF Indicated Bulk Food Price - Expected Bulk Food Price > 0 THEN
  (Indicated Bulk Food Price - Expected Bulk Food Price) / Expected Bulk Food Price Adjustment Time Up ELSE
  (Indicated Bulk Food Price - Expected Bulk Food Price) / Expected Bulk Food Price Adjustment Time Down

  Expected Bulk Food Price Adjustment Time Up = Constant.

  Expected Bulk Food Price Adjustment Time Down = Constant.

7.9.3 Parameter Setting and Module Calibration

The parameter settings in Bulk Olive Oil Price Setting module can be summarized as below:

- For the initial values of Expected Bulk Food Price and Perceived Fruit Price, historical values of Bulk Olive Oil Price and Olive Fruit Price in September 2007 are used.

- Bulk Food Export Price Perception Time is set to 3 Months whereas Fruit Price Perception Time and Perceived Retail Price Adjustment Time are set to 0.5 Months each. It is assumed that the domestic price levels along the chain are perceived in a very short time, whereas the export price level is perceived in a slightly longer time.

- Reference Fixed Cost of Processing, Variable Cost of Processing and Financial Aid for Fruit Processing are calculated with the data given in their reference sources as explained in Section 7.9.1 and embedded to the model as exogenous variables. Their values in time series can be seen in Figure 7.18. For their future values, appropriate forecasting models based on their historical data are used.

- All reference adjustment times in the module, Reference Bulk Food Price Adjustment Time, Reference Profitability of Processing Adjustment Time and Reference Retail Price Adjustment Time are assumed to be 12 Months.

- Reference Harvest Volume for Fixed Cost of Processing is set to historical harvest volume in 2015-2016 harvest season, since the Reference Fixed Cost of Processing is normalized for that harvest year.

- Expected Bulk Food Price Adjustment Time Up, Expected Bulk Food Price Adjustment Time Down, Reference Supply Demand Ratio, Sensitivity of Bulk Food Price to Retail Price, Sensitivity of Bulk Food Price to Packaging Profitability, Sensitivity of Bulk Food Price to Supply Demand Ratio, Sensitivity of Bulk Food Price to Export Price, Sensitivity of Bulk Food Price to Processing Costs and Sensitivity of Fixed Cost to Harvest Volume are determined as the solution of the calibration problem which minimizes "the sum of squared errors between the monthly bulk olive oil price generated by the model and the historical data of monthly bulk olive oil price". The details of the calibration problem are given below.

Calibration Problem for Bulk Olive Oil Price Setting Module:

Minimize
$\sum(\text{Monthly Bulk Olive Oil Price}_M - \text{Monthly Bulk Olive Oil Price}_H)^2$
subject to

$$1 \leq \text{Expected Bulk Food Price Adjustment Time Up} \leq 12$$

$$1 \leq \text{Expected Bulk Food Price Adjustment Time Down} \leq 12$$
$$0.8 \leq \text{Reference Supply Demand Ratio} \leq 1.3$$
$$0.1 \leq \text{Sensitivity of Bulk Food Price to Retail Price} \leq 0.9$$
$$0.1 \leq \text{Sensitivity of Bulk Food Price to Packaging Profitability} \leq 0.9$$
$$-0.9 \leq \text{Sensitivity of Bulk Food Price to Supply Demand Ratio} \leq -0.1$$
$$0.1 \leq \text{Sensitivity of Bulk Food Price to Export Price} \leq 0.9$$
$$0.1 \leq \text{Sensitivity of Bulk Food Price to Processing Costs} \leq 0.9$$
$$-0.5 \leq \text{Sensitivity of Fixed Cost to Harvest Volume} \leq -0.1$$

Calibration Checklist for Bulk Olive Oil Price Setting Module:

- **Statement and Compatibility of Dynamic Hypothesis and Reference Mode:** Bulk Olive Oil Price is expected to depend not only on operational costs and raw material cost (olive fruit price), but also on price levels in the following stages of the chain, which are retail price and bulk olive oil export price. Additionally, Bulk Olive Oil Price is expected to depend on supply and demand ratio in the form of the ratio of total average supply to total average demand.

- **Usage of all available knowledge about the system parameters:** In Bulk Olive Oil Price Setting module calibration; historical fruit prices, historical retail prices, historical costs, historical export prices and historical total supply and total demand amounts are used.

- **Building the smallest possible calibration problem:** The smallest possible calibration problem is achieved by considering monthly error in bulk olive oil prices. Majority of the adjustment times and perception times are presumably set before the calibration problem to reduce the problem size.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** Expected Bulk Food Price Adjustment Times are found to be smaller than those of Fruit Price setting, which is expected. Reference Supply Demand Ratio is expected to be closer to 1, which is found to be 0.956. In terms of magnitudes, sensitivity values are closer to each other and do not take very high values. We are aware of the fact that some of effect functions in Bulk Food Price are correlated (for instance, Effect of Retail Price on Bulk

Price and Effect of Packaging Profitability on Bulk Food Price). Hence, it is normal for such sensitivity parameters to have smaller values as their number is increasing within a module.

- **Calibration of initial conditions:** Initial conditions of Expected Bulk Food Price and Perceived Fruit Price are not required to be calibrated, since historical values of Bulk Olive Oil Price and Olive Fruit Price in September 2007 are used. Yet, Reference Supply and Demand Ratio is calibrated within the calibration problem described above.

- **Searching for alternative structures:** As alternative structures, Effect of Packaging Profitability on Bulk Food Price and Effect of Harvest Volume on Fixed Cost are added to the model. Additionally, in order to build an asymmetric structure for Expected Bulk Food Price, adjustment time is split into two components as Expected Bulk Food Price Adjustment Time Up and Expected Bulk Food Price Adjustment Time Down.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.7.

After setting the parameters, the resulting partial model test result for Bulk Olive Oil Price can be seen in Figure 7.19. MAPE between model generated results and historical values is 5.8%.

Table 7.7: Bulk Food Price Setting Variables - Parameter Settings

Converter	**Reference**
Expected Bulk Food Price (t_0) = 4.441 (TRY / Kg)	TÜİK
Perceived Fruit Price (t_0) = 1.602 (TRY / Kg)	TÜİK
Bulk Food Export Price Perception Time = 3 (Months)	Assumed
Expected Bulk Food Price Adjustment Time Down = 11.1 (Months)	Calibrated
Expected Bulk Food Price Adjustment Time Up = 1.36 (Months)	Calibrated

Continued on next page

Table 7.7 – *Continued from previous page*

Converter	Reference
Financial Aid for Fruit Processing = Historical Data (TRY / Kg)	TÜİK
Reference Fixed Cost of Processing = Historical Data (TRY / Kg)	IOC & TÜİK
Variable Cost of Processing = Historical Data (TRY / Kg)	IOC & TÜİK
Fruit Price Perception Time = 0.5 (Months)	Assumed
Perceived Retail Price Adjustment Time = 0.5 (Months)	Assumed
Reference Bulk Food Price Adjustment Time = 12 (Months)	Assumed
Reference Profitability of Processing Adjustment Time = 12 (Months)	Assumed
Reference Retail Price Adjustment Time = 12 (Months)	Assumed
Reference Harvest Volume for Fixed Cost of Processing = 1,700,000 (Kg)	TÜİK
Reference Supply Demand Ratio = 0.956 (Dimensionless)	Calibrated
Sensitivity of Bulk Food Price to Retail Price = 0.112 (Dimensionless)	Calibrated
Sensitivity of Bulk Food Price to Export Price = 0.104 (Dimensionless)	Calibrated
Sensitivity of Bulk Food Price to Packaging Profitability = 0.1 (Dimensionless)	Calibrated
Sensitivity of Bulk Food Price to Supply Demand Ratio = -0.1 (Dimensionless)	Calibrated
Sensitivity of Bulk Price to Processing Costs = 0.1 (Dimensionless)	Calibrated
Sensitivity of Fixed Cost of Processing to Harvest Volume = -0.1 (Dimensionless)	Calibrated

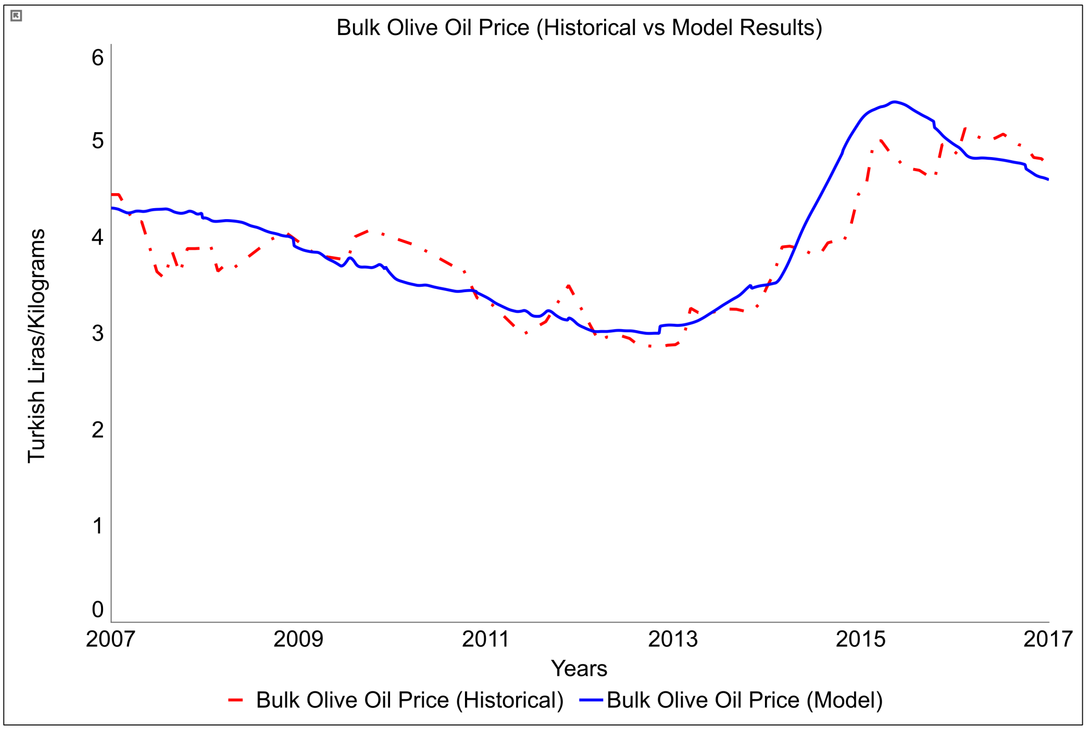

Figure 7.19: Historical Values and Model Results for Bulk Olive Oil Price, 2007-2017

7.10 Retail Price Setting

7.10.1 Data Analysis and Implications

Similar to Fruit Price Setting and Bulk Food Price Setting modules, we experience several issues about the data availability on olive oil packaging costs over the time horizon of the model. Before investigating the data in Figure 7.20, we should explain the source and the structure of Variable and Fixed Cost of Packaging.

Variable and Reference Fixed Cost of Packaging: Variable cost of packaging consists of collection logistics, packing and packaging, storage and distribution logistics costs. On the other hand, fixed cost of packaging mainly consists of machine cost, and business and financial costs. Unfortunately, packaging cost data are not available in historical time series. Only one point of data is available for 2015-2016 harvest season, which is equal to 5.63 TRY/Kg as published by the Ministry of Agriculture and Livestock (2016). Hence, we have to use proxies in order to capture the historical change of variable and fixed costs of packaging. The procedure below is followed in order to have a historical set of variable and fixed costs of packaging:

1. First, 5.63 TRY/Kg is converted into real price according to Producer Price Index (2003=100) during 2015-2016 harvest season (from 2015 October to 2016 September), which is then equal to 2.22 TRY/Kg in real terms. This value is used as the anchor for packaging cost.

2. According to olive oil value chain analysis conducted in Spain (IOC, 2015), approximately 68% of unit total cost of packaging is variable cost and 32% of it is fixed cost. This information is utilized in the distribution of total cost among fixed costs and variable costs. Then, anchor value for variable packaging cost is calculated as 2.22 * 0.68 = 1.51 TRY/Kg and reference fixed cost of packaging is calculated as 2.22 * 0.32 = 0.71 TRY/Kg.

3. For the projections of Variable and Reference Fixed Costs of Packaging throughout the time horizon of the model, changes in real values of gasoline prices are used.

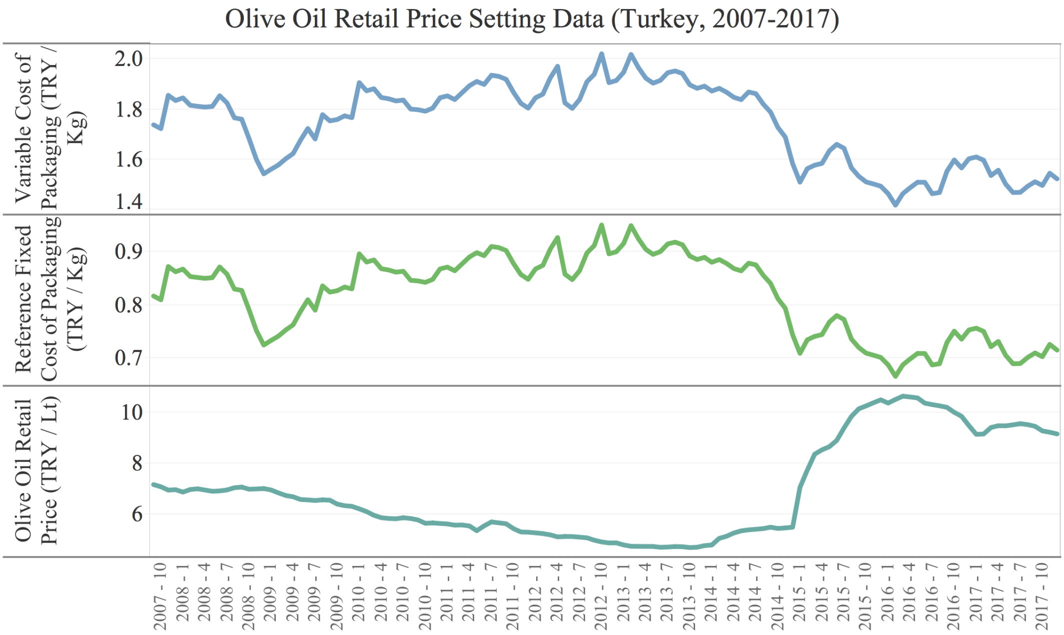

Figure 7.20: Olive Oil Retail Price Setting Data in Turkey, 2007-2017

Major observations gathered from Figure 7.20 can be summarized as follows:

- Variable Cost of Packaging and Reference Fixed Cost of Packaging have the same patterns, since their projections are calculated depending on the same indexes. The Reference Fixed Cost of Processing is adjusted and converted to Fixed Cost of Packaging depending on the input volume of packaging operations (for more information see section 7.10.2).
- Surprisingly, retail price shows a significant increase whereas packaging costs are decreasing in recent years. This observation indicates that, the increase in retail prices stems from reasons other than costs. Hence, Sensitivity of Retail Price to Packaging Costs is not expected to be very strong.

7.10.2 Model Structure Improvements for Application

In application of Olive Oil Retail Price Setting module, a set of structural improvements and modifications are made. They can be explained as follows:

- Similar to the structure added in Fruit Price Setting and Bulk Food Price Setting modules, Effect of Processed Bulk Food Volume on Fixed Cost of Packaging is added to the model. In the generic model, unit cost of packaging operations remains constant irrespective of the input amount, i.e. processed olive oil amount. In order to reflect the "economies of scale" as in Fruit Price Setting and Bulk Food Price Setting modules, Effect of Processed Bulk Food Volume on Fixed Cost of Packaging is defined in such a way that Fixed Cost of Packaging is decreasing with increasing Total Bulk Food Amount. The mathematical formulations are modified as below:

  Fixed Cost of Packaging = Reference Fixed Cost of Packaging * Effect of Processed Bulk Food Volume on Fixed Cost of Packaging

  Reference Fixed Cost of Packaging = Graphical Historical Data.

  Effect of Processed Bulk Food Volume on Fixed Cost of Packaging = (Total Bulk Food / Reference Bulk Food Volume for Fixed Cost) ^ Sensitivity of Fixed Cost to Bulk Food Volume

Reference Bulk Food Volume Volume for Fixed Cost = Constant.

Sensitivity of Fixed Cost to Bulk Food Volume = Constant.

- Reference Packaged Food Inventory Coverage is remodeled with an adaptive structure. The modified mathematical formulations are given below:

  Reference Packaged Food Inventory Coverage = SMTH1(Perceived Packaged Food Inventory Coverage, Reference Packaged Food Inventory Coverage Adjustment Time, Initial Reference Inventory Coverage)

  Perceived Packaged Food Inventory Coverage = SMTH1(Packaged Food Inventory Coverage, Packaged Food Inventory Coverage Perception Time)

  Reference Packaged Food Inventory Coverage Adjustment Time = Constant.

  Initial Reference Inventory Coverage = Constant.

- As in Fruit Price Setting and Bulk Food Price Setting modules, the asymmetric adjustment structure is built for Expected Retail Price. The adjustment time is split into two components: Expected Retail Price Adjustment Time Up and Expected Retail Price Adjustment Time Down, either of which is active in adjustment process depending on the direction of adjustment. The modified formulations are as follows:

  Rate of Change in Expected Retail Price =
  IF Indicated Retail Price - Expected Retail Price > 0 THEN
  (Indicated Retail Price - Expected Retail Price) / Expected Retail Price Adjustment Time Up ELSE
  (Indicated Retail Price - Expected Retail Price) / Expected Retail Price Adjustment Time Down

  Expected Retail Price Adjustment Time Up = Constant.

  Expected Retail Price Adjustment Time Down = Constant.

7.10.3 Parameter Setting and Module Calibration

- For the initial values of Expected Retail Price and Perceived Bulk Food Price, historical values of Olive Oil Retail Price and Bulk Olive Oil Price in September 2007 are used.

- Reference Fixed Cost of Packaging and Variable Cost of Packaging are calculated with the data given in their reference sources as explained in Section 7.10.1 and embedded to the model as exogenous variables. Their values in time series can be seen in Figure 7.20. For their future values, appropriate forecasting models based on their historical data are used.

- Packaged Food Export Price Perception Time is set to 3 Months whereas Bulk Food Price Perception Time is set to 0.5 Months. It is assumed that the domestic price level along the chain is perceived in a very short time, whereas the export price level is perceived in a slightly longer time.

- Packaged Food Inventory Coverage Adjustment Time is set to 3 Months since information about the olive oil inventory is not always readily available and the perception of inventory coverage is slower.

- Reference Packaged Food Inventory Coverage Adjustment Time is set to a very high value, 60 Months. The reason is that, reference inventory coverage is normally expected to be constant, whereas the data analysis reveals that reference inventory coverage slowly changes. Hence, Reference Packaged Food Inventory Coverage Adjustment Time is set to 60 Months.

- Reference Profitability Adjustment Time is assumed to be 12 Months.

- Reference Bulk Food Volume (for Fixed Cost of Packaging) is set to historical bulk olive oil production volume in 2015-2016 harvest season, since the Reference Fixed Cost of Packaging is normalized for that harvest year.

- Expected Retail Price Adjustment Time Down, Expected Retail Price Adjustment Time Up, Initial Reference Inventory Coverage, Sensitivity of Retail Price to Export Price, Sensitivity of Retail Price to Inventory Coverage, Sensitivity of Retail Price to Packaging Costs and Sensitivity of Fixed Costs to Bulk Food Volume are determined as the solution of the calibration problem which minimizes “the sum of squared errors between the monthly olive oil retail price generated by the model and the historical data of monthly olive oil retail price". The details of the calibration problem is given below.

Calibration Problem for Olive Oil Retail Price Setting Module:

Minimize

$\sum(\text{Monthly Olive Oil Retail Price}_M - \text{Monthly Olive Oil Retail Price}_H)^2$

subject to

$$1 \leq \text{Expected Retail Price Adjustment Time Down} \leq 12$$
$$1 \leq \text{Expected Retail Price Adjustment Time Up} \leq 12$$
$$0.5 \leq \text{Initial Reference Inventory Coverage} \leq 1.5$$
$$0.5 \leq \text{Sensitivity of Retail Price to Export Price} \leq 0.9$$
$$-0.9 \leq \text{Sensitivity of Retail Price to Inventory Coverage} \leq -0.05$$
$$0.1 \leq \text{Sensitivity of Retail Price to Packaging Costs} \leq 0.9$$
$$-0.5 \leq \text{Sensitivity of Fixed Costs to Bulk Food Volume} \leq -0.1$$

Calibration Checklist for Olive Oil Retail Price Setting Module:

- **Statement and Compatibility of Dynamic Hypothesis and Reference Mode:** Olive Oil Retail Price is expected to depend not only on operational costs and raw material cost (bulk olive oil price), but also on packaged olive oil export price. Additionally, Olive Oil Retail Price is expected to depend on supply and demand ratio in the form of inventory coverage. The strength of this dependency is expected to be much smaller than the similar effect in Bulk Olive Oil Price Setting, which is Effect of Supply Demand Ratio on Bulk Food Price.
- **Usage of all available knowledge about the system parameters:** During the calibration of Olive Oil Retail Price Setting modules, historical export prices and quantities, historical bulk olive oil prices and historical cost values are used.
- **Building the smallest possible calibration problem:** The smallest possible calibration problem is achieved by considering monthly error in olive oil retail prices. Similar to Bulk Olive Oil Price Setting module, majority of the adjustment times and perception times are presumably set before the calibration problem to reduce the problem size.

- **Feasibility of the parameters:** Feasibility of the parameters are satisfied.

- **Consistency of the parameters:** Expected Bulk Food Price Adjustment Times are found to be the smallest as expected. Sensitivity to Export Price is at its upper bound whereas Sensitivity to Inventory Coverage is at its lower bound. The fact that Sensitivity to Export Price being larger than Sensitivity to Inventory Coverage is expected, but the large gap between these two values may seem unexpected at first glance. When we investigate the normalized results of the effect functions, we find out that the gap is not huge: Effect of Inventory Coverage on Retail Price takes values between (0.936, 1.052) and Effect of Export Price on Retail Price takes values between (0.947, 1.183).

- **Calibration of initial conditions:** Initial conditions of Expected Olive Oil Retail Price and Perceived Bulk Olive Oil Price are not required to be calibrated, since historical values of Olive Oil Retail Price and Bulk Olive Oil Price in September 2007 are used. Yet, Initial Reference Inventory Coverage is calibrated within the calibration problem described above.

- **Searching for alternative structures:** As alternative structures, Effect of Processed Bulk Food Volume on Fixed Cost is added to the model. Reference Packaged Food Inventory Coverage is remodeled with an adaptive structure and it is updated with Packaged Food Inventory Coverage realizations. Additionally, in order to build an asymmetric structure for Expected Olive Oil Retail Price, adjustment time is split into two components as Expected Retail Price Adjustment Time Up and Expected Retail Price Adjustment Time Down.

- **Documentation of calibration problem:** Calibration problem is documented.

For the complete parameter settings and their references, see Table 7.8.

After setting the parameters, the resulting partial model test result for Olive Oil Retail Price can be seen in Figure 7.21. MAPE between model generated results and historical values is 5.4%.

In this chapter, we present how the parameter settings and partial calibrations are conducted for each module. The connected version of the model, where all modules

Table 7.8: Retail Price Setting - Parameter Setting

Converter	Reference
Expected Retail Price (t_0) = 7.16 (TRY/Lt)	TÜİK
Perceived Bulk Food Price (t_0) = 4.44 (TRY/Kg)	TÜİK
Expected Retail Price Adjustment Time Down = 3.68 (Months)	Calibrated
Expected Retail Price Adjustment Time Up = 1.90 (Months)	Calibrated
Initial Reference Inventory Coverage = 0.5 (Months)	Calibrated
Reference Fixed Cost of Packaging = Historical Graphical Data	IOC & TÜİK
Variable Cost of Packaging = Historical Graphical Data	IOC & TÜİK
Bulk Food Price Perception Time = 0.5 (Months)	Assumed
Packaged Food Export Price Perception Time = 3 (Months)	Assumed
Packaged Food Inventory Coverage Adjustment Time = 3 (Months)	Assumed
Reference Packaged Food Inventory Coverage Adjustment Time = 60 (Months)	Assumed
Reference Profitability Adjustment Time = 12 (Months)	Assumed
Reference Bulk Food Volume = 160000 (K Tonnes)	IOC
Sensitivity of Retail Price to Export Price = 0.90 (Dimensionless)	Calibrated
Sensitivity of Retail Price to Inventory Coverage = -0.05 (Dimensionless)	Calibrated
Sensitivity of Retail Price to Packaging Costs = 0.218 (Dimensionless)	Calibrated
Sensitivity of Fixed Costs to Bulk Food Volume = -0.50 (Dimensionless)	Calibrated

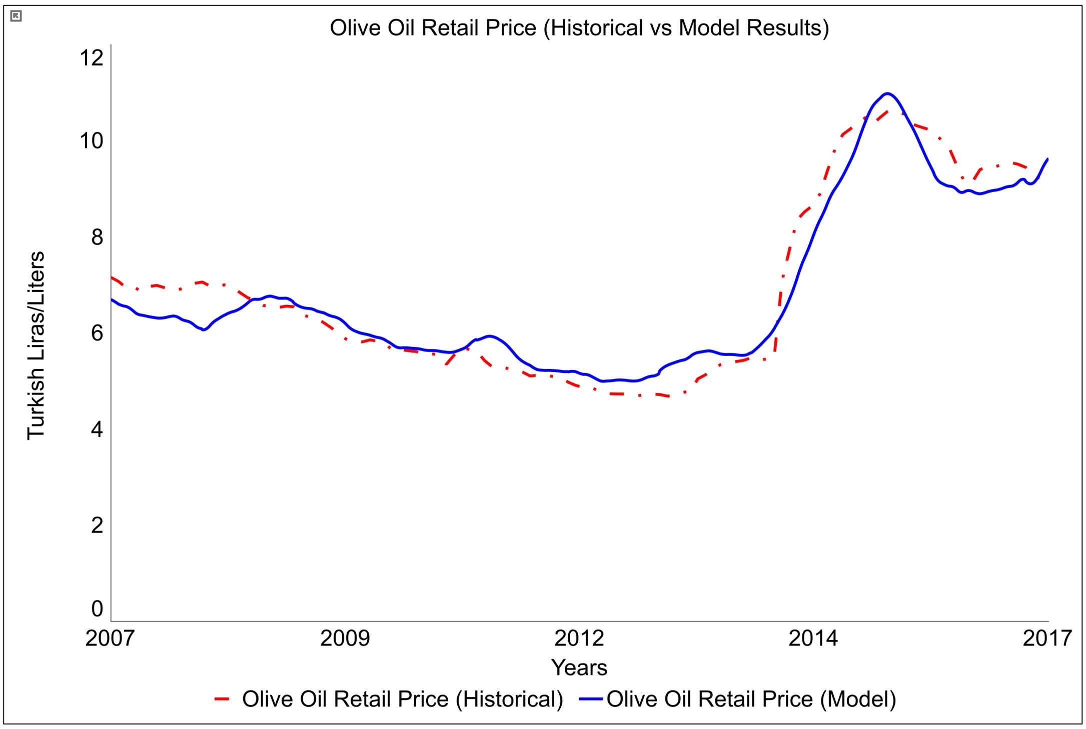

Figure 7.21: Historical Values and Model Results for Olive Oil Retail Price, 2007-2017

feed each other with their endogenously generated variables, is presented in Behavior Reproduction Test in Chapter 8 with other relevant model validation tests.

CHAPTER 8

AGRICULTURAL VALUE CHAIN MODEL VALIDATION

In this chapter, we explain how appropriate model validation tests are applied to Olive Oil Value Chain Model described in Chapter 7. First, overview of the related literature on system dynamics model validation is summarized. Then, the details of appropriate Direct Structure Tests, Structure-oriented Behavior Tests and Behavior Pattern Tests are presented with their applications to our model.

It should be stated that model validation is a very iterative and elongated process. As you may guess, our model was not able to pass all of these tests at the first trial. Yet, we iteratively solve the issues, improve the model structure where needed and reconduct the relevant tests. In this chapter, we summarize the test results of the final version of our model.

8.1 Literature Review on System Dynamics Model Validity

During both model building and model validation phases, we use some fundamental guidelines in the literature of system dynamics model validation. Before proceeding with our model validation tests, we present an overview of system dynamics model validation literature.

We start our overview with very fundamental works on system dynamics model validity which are published in 90's: Barlas and Carpenter (1990) discuss the philosophical roots of system dynamics model validation. They compare "the traditional logical empiricist philosophy of science" and "the relativist philosophy of science" in their approaches to model validation. They show that recent relativist philosophy of science is consistent with the system dynamics approach and emphasize that the validity of a system dynamics model is related with its goal. Then, in his two complementary papers (Barlas (1994) and Barlas (1996)), Barlas provides solid guidelines in system dynamics model validation and presents the logical order of relevant validity tests. Since then, especially the guidelines presented in Barlas (1996) (Citations: 1,424, Source: Google Scholar, Online Access: May 2019) are used widely in system dynamics applications. Groesser and Schwaninger (2012) state that " It was Barlas (1996) who first suggested a validation process with three stages: empirical and theoretical direct structure tests, then structure-oriented behavior tests, and finally behavior pattern tests." First two set of tests mainly focuses on structural validity of model whereas the final group of tests focus on performance of the model in reproducibility of real world dynamics. In our model validity test, we generally follow the guidelines presented in Barlas (1996). The application details of these tests are given in the following sections.

Other readings on structural validation of system dynamics models can be summarized as follows: two complementary papers on structural validity of system dynamics models, Qudrat-Ullah (2005) and Qudrat-Ullah and Seong (2010), emphasize the importance of structural validity and demonstrate the application of structural validity tests in system dynamics modeling in electricity and energy policy domains. In another insightful study, Saysel and Barlas (2006) present a simplified and generic version of a large and case-specific system dynamics model, and illustrate the details of applications of structural model validity tests to the simplified version. In that way, they show that the simplified model, which is "suitable for transferring knowledge in the same domain and useful for disseminating the essential structures responsible for the problematic behavior and mismanagement", is still valid and useful as the original one. In our study, we follow the same idea but in the reverse order: we first build the generic and simplified version of our model as "Agricultural Commodity Value Chain Model" and then enlarge and improve it to obtain "Turkish Olive Oil Value Chain Model".

A group of studies in system dynamics model validation literature focuses on structure oriented behavior patterns and automated calibration of parameters. Barlas and Kanar (2000) proposes a computerized algorithm for structure oriented behavior tests which compares the anticipated behavior and the resulting behavior of the model under specific conditions. They use Hidden Markov Models to define the anticipated behavior, and in order to determine the class that the resulting data belong to, they make comparisons by calculating optimum likelihoods. In another work, Boğ and Barlas (2005) also use Hidden Markov Model based pattern recognition and present a software which performs automated calibration parameters for a desired dynamic behavior pattern. They demonstrate how this software can be used both in model validity tests and parameter calibration. In a later study, Yücel and Barlas (2011) present an automated and efficient parameter search approach which is called pattern-oriented parameter specifier (POPS). These studies are very insightful in terms of their implications on structure oriented behavior validity tests, yet they could not be directly implemented to our value chain model validity tests, since those approaches require the specification of "desired behavior patterns from a set of the basic patterns library" defined/recognized by those software or algorithms.

On behavioral (output) validity, Barlas (1990) states that "point comparison" is not appropriate in continuous simulation and behavioral validity tests question "if the model is able to reproduce the dynamic time patterns that have been observed in the behavior of the real system." In line with that purpose, Barlas proposes an output validity test which consists of comparing the auto-correlation functions of the observed and model-generated outputs. Sücüllü and Yücel (2014) also emphasize that in pattern-based evaluation of system dynamics model outputs, the characteristics of behavior patterns are more important than point-by-point error calculations. In their paper, they present their software, Behavior Analysis and Testing Software (BATS), which performs pattern-based evaluation methods for model analysis. Yet, since the software is developed for analysis of steady-state periodic behaviors, we are not able to use it in our value chain model analysis.

In a very insightful paper entitled "Model calibration as a testing strategy for system dynamics models", Oliva (2003) presents the theory behind the automated calibration and also proposes heuristics to use calibration as a testing framework. In Chapter 7, our calibration models and calibration checklists are mainly based on the heuristics and analysis in Oliva (2003). Our calibration checklists in Chapter 7 constitute our parameter confirmation tests as a direct structure test.

In his book, Sterman (2000) presents a comprehensive chapter on validation and model testing. He gives the purposes of each test in detail and provides tools, procedures and examples to perform each test. As stated earlier, in model validation tests for our study, we generally follow the concrete guidelines presented in Barlas (1996) and Sterman (2000). The types, details and results of our model validation tests are presented in the following sections.

8.2 Direct Structure Tests

Direct Structure Tests focus on evaluating the model structure. At that stage, no simulation run is involved. All relationships in the model are treated individually and compared with available knowledge in the real system or in the literature. As direct structure tests, we conduct Structural Confirmation Tests, Parameter Confirmation Tests, Direct Extreme Conditions Tests and Dimensional Consistency Tests. The details and the results of the tests are presented in the following subsections.

8.2.1 Structural Confirmation Tests

Structural confirmation tests aim to confirm the form of the equations in the model by comparing them with the available knowledge about the system. They are highly qualitative type of tests in nature. Structural confirmation tests can be applied both at empirical and theoretical levels. Empirical structural confirmation tests focus on comparing the model equations with the relationships that exist in the real world system. On the other hand, theoretical structural confirmation tests consist of comparing the form of the model equations with the generalized knowledge in the literature. During model formulation and model tests, we utilize both forms of these tests. The main sources we use for structural confirmation tests are as follows:

- Relevant system dynamics and economics literature (especially the mathematical modeling studies in Generic Commodity Market Modeling),
- Historical dynamic data analysis (i.e. investigating the behavior of the interrelated data over time),

- Information about the agricultural value chains and the Turkish olive oil value chain, that is gathered from reports published by local and global institutions,
- Interviews with stakeholders,
- Surveys conducted with the stakeholders.

8.2.2 Parameter Confirmation Tests

Parameter confirmation tests focus on inquiring the consistency of parameter values with relevant descriptive and numerical knowledge of the real world system. Additionally, one should be able to confirm that each parameter in the model has a real world counterpart. During the partial calibration tests presented in Chapter 7, we conduct parameter confirmation tests for each parameter by examining the feasibility and consistency of the parameter. Additionally, we can state that, no artificial coefficients or parameters are used in the model other than the variables presented.

8.2.3 Direct Extreme Condition Tests

In direct extreme condition tests, we check whether each single equation makes sense even when its inputs take on extreme values. Without any simulation runs, we take each equation individually, set its inputs to extreme values, anticipate on the output results, and compare the value of the output with our anticipation. For instance, if there is no Mature Trees, there should be no available fruits to be harvested. Yet, on the other hand, if Financial Supports for Planting drop to 0, Effect of Planting Financial Supports on Tree Stocks is not expected to be 0, because farmers do not immediately give up all of their trees due to loss of Financial Supports. Hence, it is expected to be smaller than but closer to 1. With similar anticipations and comparisons, we check each equation in the model individually and make proper modifications where needed, and then repeat the tests. We can give an example of these modifications:

Effect of Planting Costs on Tree Stocks: In Agricultural Commodity Value Chain Model presented in Chapter 5, we build the function as follows:

Effect of Planting Costs on Tree Stocks = (Planting Costs / Reference Planting Costs) ^ Sensitivity of Tree Stocks to Planting Costs

This function passes the Direct Extreme Condition Test under the assumption of "Planting Costs can never be absolute 0". This assumption is proper for the initial numerical study conducted in Chapter 6. Yet, when we adapt the model to Olive Oil Value Chain in Turkey, we relax this assumption, define a new variable "Maximum of Effect of Planting Cost" and modify the function as follows:

Effect of Planting Costs on Tree Stocks =
IF Planting Costs = 0 THEN Maximum of Effect of Planting Costs
ELSE MIN(Maximum of Effect of Planting Costs, (Planting Costs / Reference Planting Costs) ^ Sensitivity of Tree Stocks to Planting Costs)

Hence, the formulation becomes valid even if Planting Costs are absolute 0.

8.2.4 Dimensional Consistency Tests

Dimensional consistency test aims to check whether each equation in the model is dimensionally consistent without the use of parameters having no real world meaning. We check each equation for dimensional consistency and our model passes this test. Additionally, system dynamics modeling software (including Stella) have health-check systems to warn modelers in case of dimensional inconsistencies. Our models run without any warnings.

8.3 Structure-Oriented Behavior Tests

Structure-Oriented Behavior Tests focus on evaluating the model structure indirectly, by considering the model-generated behavior patterns. At that stage, simulation is involved including either the whole model or only some modules. As for the indirect structure tests, we conduct Extreme Condition Tests and Behavior Sensitivity Tests. The details and the results of the tests are presented in the following sections.

8.3.1 Extreme Condition Test

In Extreme conditions test, we run the complete simulation model after setting selected parameters to extreme values, and comparing model results with our anticipations on the model behavior. In Direct Extreme Condition tests explained in Section 8.2.3, we consider one equation at a time and no simulation run is involved. Yet, in Extreme Condition tests, we run the whole simulation model and check if the model results are consistent with the anticipated model behavior. The Extreme Condition Test Cases we conduct can be seen in Table 8.1.

We can exemplify the test procedure as follows: consider the extreme condition test case of initial conditions of Young Trees. Before conducting runs, we write down the anticipated results of the extreme case: "When initial level of Young Trees is very low, Mature Tree level stays closer to the base run in the initial periods, but as time passes, Mature Tree level falls below to its base run results since there is not enough Young Trees to be mature. Hence, prices follow the same pattern of the base run in the initial periods, but then rises due to low level of supply." Then we make runs by setting all tree stocks of Young Trees (t_0) = 0. As we observe that the resulting model behavior matches with our anticipation, we move on to the next extreme case.

The model behavior results of almost all extreme condition test cases are found to be consistent with the anticipated results. In case of inconsistencies, we iteratively check and modify the model structure where required. For instance, in Planting module, Effect of Growing Costs on Desired Tree Stock Level is added to the model as a result of the extreme condition test of Fixed Cost of Growing and Financial Cost of Growing. The other effects on Desired Tree Stock Level were satisfactorily good at replicating the real world behavior of Young Trees and Mature Trees. Yet, when we consider the case of "what if the government supports growing operations in very high levels and cost of growing becomes zero?", we realized that Effect of Growing Costs on Desired Tree Stock Level should be added to the model structure for the sake of completeness.

When all extreme cases are considered, two extreme cases do not produce the anticipated results due to the structure of the model. These are to be stated as the limitations of the model in two specific cases:

- **GDP:** When GDP is very low, we expect that people give up consuming olive oil and the quantity demanded immediately falls to very low levels. Yet, when the historical data are analyzed, GDP is found not to be very effective on olive oil demand and Sensitivity of Demand to GDP is set to 0.05. Hence, when GDP approaches to 0, the quantity demanded decreases, but does not approach to 0. That is, policy analysis for the case of very low levels of GDP would not produce meaningful results.
- **Population:** In a similar manner, when Population is very low, we expect that quantity demanded also becomes very low, and in a short time, producers give up producing olive oil. In the model, the quantity demanded becomes very low in case of low Population, but olive oil production does not come to a halt. The reason is that, the olive oil supply chain structure is of "push" type rather than "pull" type. Hence, even if consumption is very low, producers keep on producing olive oil as long as it is profitable to do so. That is, policy analysis for the case of very low levels of Population may not produce meaningful results.

If policy analysis is required for very low levels of GDP or Population, these limitations can be resolved by defining table functions or piecewise functions between the related cause-and-effect relationships.

8.3.2 Behavior Sensitivity Test

Behavior sensitivity tests focus on determining the parameters to which the model results are sensitive and questioning whether these sensitivities would be observed in the real world. For this purpose, behavior sensitivity tests are conducted for each exogenously set and/or calibrated parameter. These parameters are altered within their own -20% - +20% range and the resulting fruit price, bulk food price and retail price behaviors are recorded. The parameters which result in MAPE larger than 5% are classified as "model is sensitive to". These parameters, their test ranges and resulting MAPE values for Fruit Price, Bulk Food Price and Retail Price are presented in Tables 8.2, 8.3 and 8.4, respectively.

Table 8.1: Extreme Condition Test Cases

Module	**Variable**	**Model Value**	**Extreme Condition**	**Extreme Value**
Planting	Mature Trees (t_0)	104,219	Very low	25,000
Planting	Mature Trees (t_0)	104,219	Very high	10,000,000
Planting	Young Trees (t_0)	13,370	Very low	0
Planting	Young Trees (t_0)	13,370	Very high	1,000,000
Planting	Death Fraction of Young Trees	0.003	Very high	0.5
Planting	Life Time	1,200	Very short	12
Planting	Life Time	1,200	Very long	1,200,000
Planting	Maturation Times	9.67, 22.3, 46.08	Very low	0.5
Planting	Maturation Times	9.67, 22.3, 46.08	Very high	1,200
Planting	Financial Supports for Planting	Graph	Very high	Graph*100
Planting	Financial Supports for Planting	Graph	Very low	Graph*0.01
Planting	Planting Costs	Graph	Very high	Graph*100
Planting	Planting Costs	Graph	Very low	Graph*0.01
Harvesting	Fruits per Mature Tree	Graph	Very low	Graph*0.1
Harvesting	Fruits per Mature Tree	Graph	Very high	Graph*10

Continued on next page

Table 8.1 – *Continued from previous page*

Module	**Variable**	**Model Value**	**Extreme Condition**	**Extreme Value**
Harvesting	Expected Olive Usage Amount for Other Means	Equation	Very low	Equation*0.01
Harvesting	Expected Olive Usage Amount for Other Means	Equation	Very high	Equation*100
Processing	Processed Bulk Food Inventory	30,000	Very low	300
Processing	Processed Bulk Food Inventory	30,000	Very high	3,000,000
Processing	Processing Yield	Graph	Very low	Graph*0.3
Processing	Processing Yield	Graph	Very high	Graph*5
Packaging	Packaged Food Inventory	15,000	Very low	150
Packaging	Packaged Food Inventory	15,000	Very high	1,500,000
Packaging	Packaging Time	0.5	Very slow	50
Packaging	Packaging Time	0.5	Very fast	0.005
Packaging	Distribution and Retailing Time	0.5	Very slow	50
Packaging	Distribution and Retailing Time	0.5	Very fast	0.005
Export	Rate of Packaged Food Export Quantity Demanded	Graph	Very low	Graph*0.01
Export	Rate of Packaged Food Export Quantity Demanded	Graph	Very high	Graph*10
Export	Rate of Bulk Food Export Quantity Demanded	Graph	Very low	Graph*0.01
Export	Rate of Bulk Food Export Quantity Demanded	Graph	Very high	Graph*10

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Table 8.1 – *Continued from previous page*

Module	**Variable**	**Model Value**	**Extreme Condition**	**Extreme Value**
Export	Packaged Food Export Price	Graph	Very low	Graph*0.01
Export	Packaged Food Export Price	Graph	Very high	Graph*10
Export	Bulk Food Export Price	Graph	Very low	Graph*0.01
Export	Bulk Food Export Price	Graph	Very high	Graph*10
Demand	Substitute Price	Graph	Very low	Graph*0.01
Demand	Substitute Price	Graph	Very high	Graph*100
Demand	GDP	Graph	Very low	Graph*0.01
Demand	GDP	Graph	Very high	Graph*100
Demand	Market Trend	Graph	Very low	Graph*0.01
Demand	Market Trend	Graph	Very high	Graph*100
Demand	Population	Graph	Very low	Graph*0.01
Demand	Population	Graph	Very high	Graph*100
Fruit Price	Variable Cost of Harvesting	Graph	Very low	Graph*0.01
Fruit Price	Variable Cost of Harvesting	Graph	Very high	Graph*5
Fruit Price	Fixed Cost of Growing	Graph	Very low	Graph*0.01
Fruit Price	Fixed Cost of Growing	Graph	Very high	Graph*100

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Table 8.1 – *Continued from previous page*

Module	**Variable**	**Model Value**	**Extreme Condition**	**Extreme Value**
Fruit Price	Financial Aid for Growing	Graph	Very low	Graph*0.01
Fruit Price	Financial Aid for Growing	Graph	Very high	Graph*100
Bulk Food Price	Variable Cost of Processing	Graph	Very low	Graph*0.01
Bulk Food Price	Variable Cost of Processing	Graph	Very high	Graph*100
Bulk Food Price	Fixed Cost of Processing	Graph	Very low	Graph*0.01
Bulk Food Price	Fixed Cost of Processing	Graph	Very high	Graph*100
Bulk Food Price	Financial Aid for Processing	Graph	Very low	Graph*0.01
Bulk Food Price	Financial Aid for Processing	Graph	Very high	Graph*100
Retail Price	Variable Cost of Packaging	Graph	Very low	Graph*0.01
Retail Price	Variable Cost of Packaging	Graph	Very high	Graph*10
Retail Price	Fixed Cost of Packaging	Graph	Very low	Graph*0.01
Retail Price	Fixed Cost of Packaging	Graph	Very high	Graph*100

Table 8.2: Behavior Sensitivity Test Results - MAPE in Fruit Prices (FP)

Module	**Variable**	**Min.**	**Max.**	**FP MAPE (Min.)**	**FP MAPE (Max.)**
Bulk Food Price	Expected Bulk Food Price (t_0)	3.55	5.33	6.7%	6.0%
Fruit Price	Expected Fruit Price (t_0)	1.28	1.92	3.54%	5.29%
Fruit Price	Sensitivity of Fruit Price to Harvest Amount	-0.29	-0.43	8.77%	7.22%
Fruit Price Setting	Variable Cost of Harvesting	Graph*0.8	Graph*1.2	32.88%	17.98%
Fruit Price Setting	Reference Fixed Cost of Growing	Graph*0.8	Graph*1.2	7.11%	6.39%
Harvesting	Reference Harvest Amount	811,394	1,217,092	17.51%	22.39%
Harvesting	Friuts per Mature Tree	Graph*0.8	Graph*1.2	8.20%	8.79%
Packaging	Reference Packaging Rate	9,927	14,891	5.27%	0.88%
Planting	Mature Trees (t_0)	83,375	125,063	36.73%	19.82%
Processing	Processing Yield	Graph*0.8	Graph*1.2	11.22%	12.52%

Table 8.3: Behavior Sensitivity Test Results - MAPE in Bulk Food Prices (BP)

Module	**Variable**	**Min.**	**Max.**	**BP MAPE (Min.)**	**BP MAPE (Max.)**
Bulk Food Price	Expected Bulk Food Price (t_0)	3.55	5.33	13.08%	12.09%
Bulk Food Price	Reference Supply Demand Ratio	0.77	1.15	13.17%	14.49%
Demand	Population	Graph*0.8	Graph*1.2	11.33%	6.43%
Fruit Price Setting	Reference Fixed Cost of Growing	Graph*0.8	Graph*1.2	5.84%	6.58%
Harvesting	Reference Harvest Amount	811,394	1,217,092	8.01%	10.56%
Harvesting	Friuts per Mature Tree	Graph*0.8	Graph*1.2	29.40%	17.20%
Packaging	Reference Packaging Rate	9,927	14,891	11.14%	2.59%
Packaging	Reference Processing Volume for Packaging Rate	127,789	191,683	2.43%	8.16%
Planting	Mature Trees (t_0)	83,375	125,063	30.94%	17.20%
Processing	Bulk Food Demand Averaging Time	9.6	14.4	12.90%	14.07%
Processing	Processing Yield	Graph*0.8	Graph*1.2	27.74%	17.30%

Table 8.4: Behavior Sensitivity Test Results - MAPE in Retail Prices (RP)

Module	**Variable**	**Min.**	**Max.**	**RP MAPE (Min.)**	**RP MAPE (Max.)**
Bulk Food Price	Expected Bulk Food Price (t_0)	3.55	5.33	6.16%	5.31%
Bulk Food Price	Reference Supply Demand Ratio	0.76	1.15	4.92%	5.90%
Demand	Reference Retail Price for Demand	6.34	9.50	5.92%	8.11%
Demand	Sensitivity of Demand to Product Availability	0.4	0.6	3.98%	6.47%
Demand	Population	Graph*0.8	Graph*1.2	13.06%	17.62%
Export	Packaged Food Export Price	Graph*0.8	Graph*1.2	4.51%	5.03%
Harvesting	Expected Olive Usage Amount for Other Means	Graph*0.8	Graph*1.2	5.40%	8.13%
Harvesting	Fruits per Mature Tree	Graph*0.8	Graph*1.2	28.47%	15.22%
Packaging	Reference Packaging Rate	9,927	14,891	15.69%	2.36%
Packaging	Reference Processing Volume for Packaging Rate	127,789	191,683	2.24%	11.54%
Planting	Mature Trees (t_0)	83,375	125,063	27.41%	14.82%
Processing	Bulk Food Demand Averaging Time	9.6	14.4	5.01%	5.75%
Processing	Processing Yield	Graph*0.8	Graph*1.2	24.06%	14.02%

When we examine tables, we observe that there are only a few "Sensitivity" parameters that the model is found to be sensitive to. That is, our model is robust to changing levels of "Sensitivity" parameters, almost all of which are found with automated calibration. The model is found to be sensitive to some "Reference" values, which is somehow expected, since these reference values are the main determinants of the regarding effect functions. Another group of parameters, which can be classified as "direct multipliers" of demand and supply volume, i.e. Population, Fruits per Mature Tree, Processing Yield etc., takes part in all three tables which is also expected.

8.4 Behavior Pattern Tests

Tests in previous sections, direct structure tests and structure-oriented behavior tests, mainly consider the structural validity of the model. As the structural validity of the model is confirmed, we move on to behavior pattern tests, which focus on the reproducibility performance of the model to the real world dynamics. In behavior pattern tests, as Barlas (1996) mention "It is crucial to note that the emphasis is on pattern prediction (periods, frequencies, trends, phase lags, amplitudes, etc.), rather than point (event) prediction." Since our problem does not involve a steady behavior, we are to make graphical comparisons between the model generated data and historical data for some selected behavior patterns measured. Additionally, we calculate MAPE between the model generated data and historical data to have an idea about the percent deviation between two data sets.

As a part of parameter setting and calibration, the results of partial module-by-module tests are presented in Chapter 7 via graphical comparisons and MAPE's for each module. Yet, for the Behavior Pattern Tests of the complete model, the procedure below is followed:

1. Instead of partially isolated module structures built for calibration, all nine modules are connected with all input-output relationships among modules.
2. The idea in our behavior pattern test is using the data between 2007-2017 to determine the model parameters and using 2007-2018 data to test the model. In that way, by adding 2018 to the time horizon of the model, we test the

performance of the model in reproducing prospective behaviors. The model parameters are presented already in Chapter 7, yet some of these exogenous variables consist of historical graphical data. Hence, as if we were at the end of year 2017 and had no information about 2018, we make forecasts for these exogenous variables which consist of historical graphical data.

3. In forecasting of exogenous variables for 2018, the rules of thumb described below are generally followed:

    - If the historical data are stationary, then single-exponential smoothing method is used. If the data show a trend, then either a linear trend model or a double-exponential smoothing method is used. If the data show recurrent cycles or patterns, triple-exponential smoothing method is used.
    - The forecasting method's smoothing coefficients are determined according to both MAPE results they generate (which is preferably under 10%), and field information and judgment on the data set (i.e. in forecasting the export quantities in the near future, we know that trend coefficients should be much smaller than the level coefficients; yet, in forecasting the market trend in the near future, trend coefficients should be closer to other coefficients, etc.). The related variables of the modules, forecasting methods and smoothing coefficients used are given in Table 8.5 where ES stands for "Exponential Smoothing", α for level, γ for trend and δ for seasonality.

4. As the last step, we run the complete model and select the control measures to test the performance of the model in reproducing the behavior patterns in the real world. As it is stated in earlier sections, the majority of the available data are reported annually. Hence, this annual aggregated data are not completely adequate to test the "behavior patterns". The only available appropriate data to test the behavior patterns are monthly reported prices. Since the data for Bulk Olive Oil Price are not available for 2018, the behavior pattern tests are conducted with Olive Fruit Price and Olive Oil Retail Price. The complete model run results for these two measures are provided in Figures 8.1 and 8.2, respectively.

Table 8.5: Graphical Variables - Information for Forecasting 2018 Data

Module	**Variable**	**Forecasting Methods**
Planting	Financial Supports for Planting	Single ES, $\alpha = 0.17$
Planting	Planting Costs	Linear Trend
Harvesting	Fruits per Mature Tree	Triple ES, $\alpha = 0.5$, $\gamma = 0.2$, $\delta = 0.1$
Processing	Processing Yield	Triple ES, $\alpha = 0.5$, $\gamma = 0.2$, $\delta = 0.1$
Demand	GDP per Capita	Linear Trend
Demand	Population	Linear Trend
Demand	Market Trend	Triple ES, $\alpha = 0.2$, $\gamma = 0.15$, $\delta = 0.15$
Demand	Substitute Price	Triple ES, $\alpha = 0.5$, $\gamma = 0.15$, $\delta = 0.10$
Export	Bulk Food Export Price	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.4$
Export	Packaged Food Export Price	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.4$
Export	Rate of Bulk Food Export Quantity Demanded	Triple ES, $\alpha = 0.5$, $\gamma = 0$, $\delta = 0.1$
Export	Rate of Packaged Food Export Quantity Demanded	Triple ES, $\alpha = 0.5$, $\gamma = 0$, $\delta = 0.1$
Fruit Price	Financial Aid for Growing	Single ES, $\alpha = 0.14$
Fruit Price	Reference Fixed Cost of Growing	Single ES, $\alpha = 0.05$
Fruit Price	Variable Cost of Harvesting	Double ES, $\alpha = 1$, $\gamma = 0.15$

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Table 8.5 – *Continued from previous page*

Module	**Variable**	**Forecasting Methods**
Bulk Food Price	Financial Aid for Fruit Processing	Double ES, $\alpha = 0.6$, $\gamma = 1$
Bulk Food Price	Reference Fixed Cost of Processing	Single ES, $\alpha = 0.98$
Bulk Food Price	Variable Cost of Processing	Single ES, $\alpha = 0.98$
Retail Price	Reference Fixed Cost of Packaging	Triple ES, $\alpha = 0.5$, $\gamma = 0.1$, $\delta = 0.1$
Retail Price	Variable Cost of Packaging	Triple ES, $\alpha = 0.5$, $\gamma = 0.1$, $\delta = 0.1$

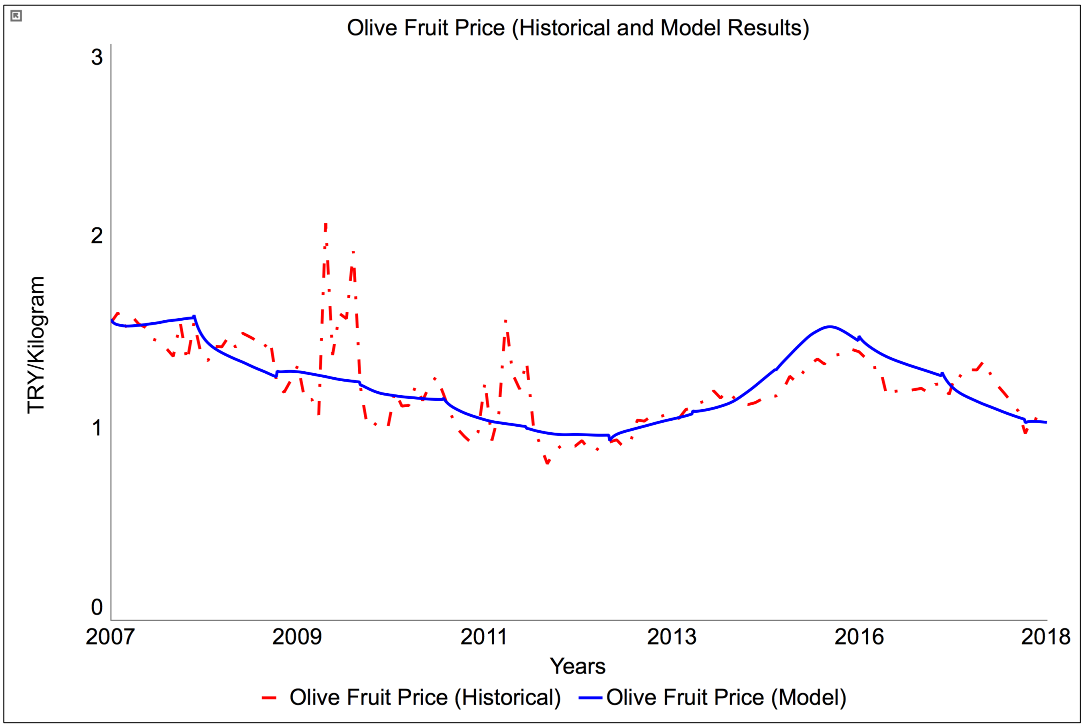

Figure 8.1: Historical Values and Model Results for Olive Fruit Prices (2007-2018)

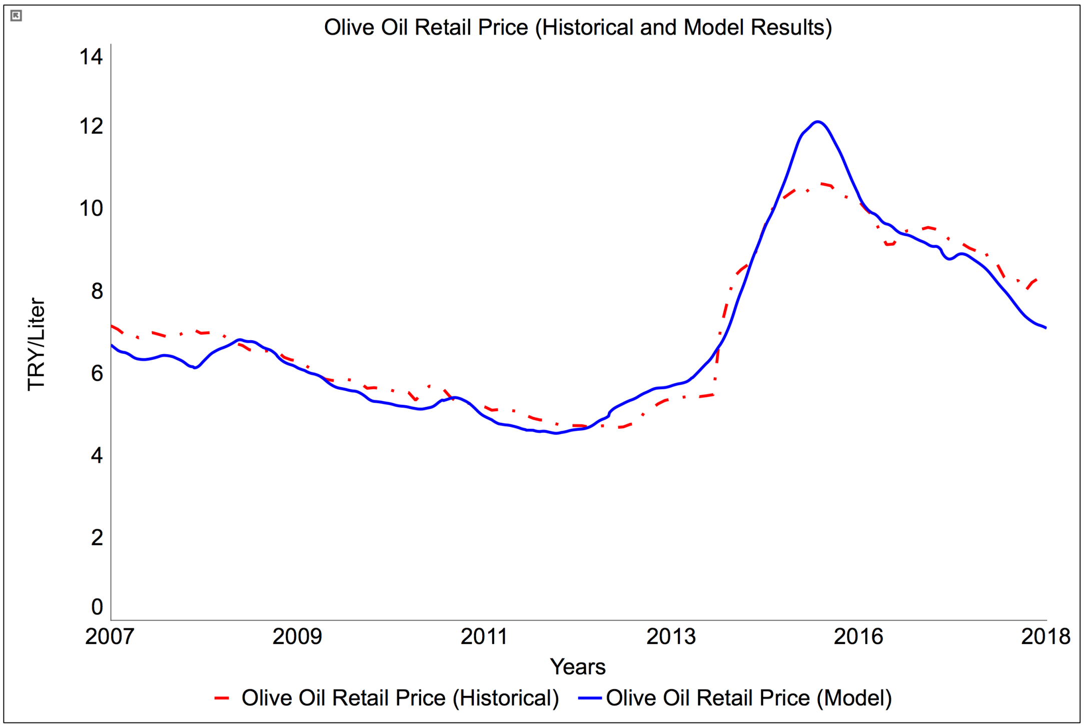

Figure 8.2: Historical Values and Model Results for Retail Prices (2007-2018)

In the graphical investigation, we can state that both measures follow their overall historical patterns, especially in terms of trends and amplitudes. In historical behavior of Olive Fruit Price, there are two groups of outliers (Figure 8.1, around 2009 and 2011) which are not captured by the model generated results. Yet, by 2012, the model generated results follow the historical pattern in a more harmonized way. When Olive Oil Retail Price in Figure 8.2 is examined, we can say that historical and model generated patterns are in a batter harmony in terms of not only general trend but also in time of peak point and times of turning points. The remarkable observation in Olive Oil Retail Price is that, amplitudes of peak levels do not exactly match and model generated peak value exceeds the historical peak value around 2015. In order to have an idea about the percent deviation between two data sets, MAPE values are calculated for the time periods of 2007-2018, 2007-2017 and 2018, separately (see Table 8.6) and all MAPE values are found to be below 10%. Considering the graphical observations as the main source and MAPE calculations as a complementary source, we can say that our model is acceptable to be useful for its purpose.

Table 8.6: Behavior Pattern Test: MAPE Results for Fruit and Retail Prices

Variable	**MAPE (2007-2018)**	**MAPE (2007-2017)**	**MAPE (2018)**
Fruit Price	8.2%	8.3%	7.7%
Retail Price	5.6%	5.6%	6.5%

Although they are not appropriate to be used for behavior pattern tests, we also calculate MAPE values for other available measures: the complete model run results of Young Trees, Mature Trees, Olive Harvest Amount, Olive Oil Processing Amount and Olive Oil Demand can be seen in Figures 8.3-8.7. Since the data for Olive Oil Packaging is not available, it could not be graphically compared for 2007-2018.

For all measures, it is good to observe that they all follow the annual trends in the historical data from one year to another (i.e. if historical data increases (decreases) from year T to T+1, model generated data also increases (decreases) from year T to T+1).

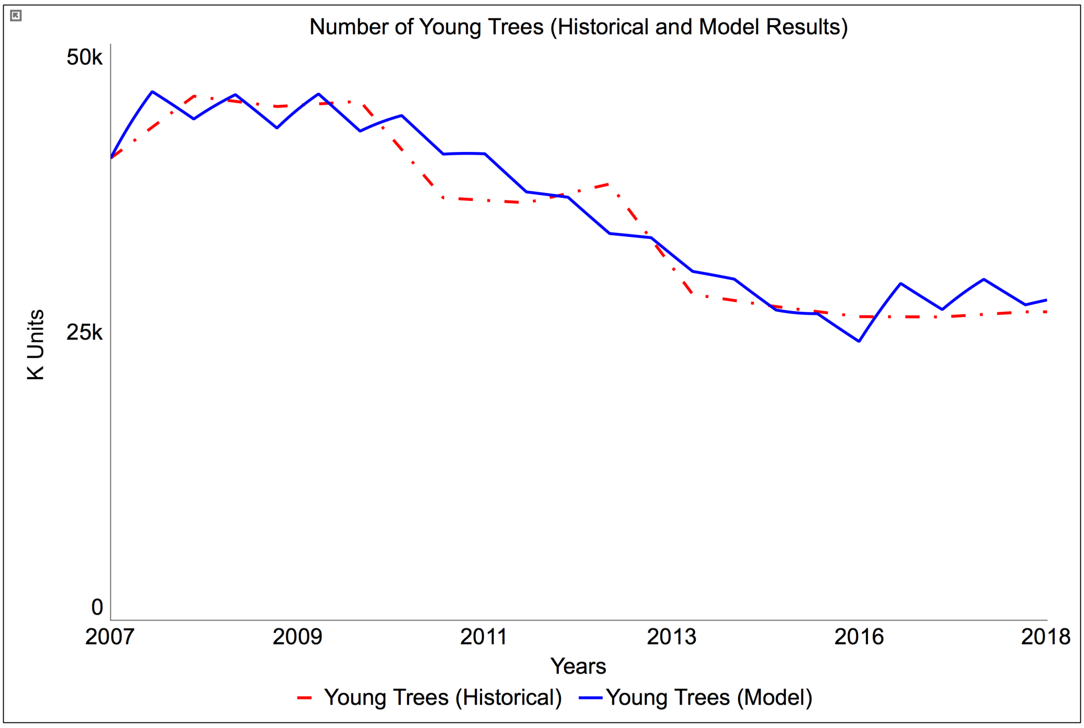

Figure 8.3: Historical Values and Model Results for Young Trees (2007-2018)

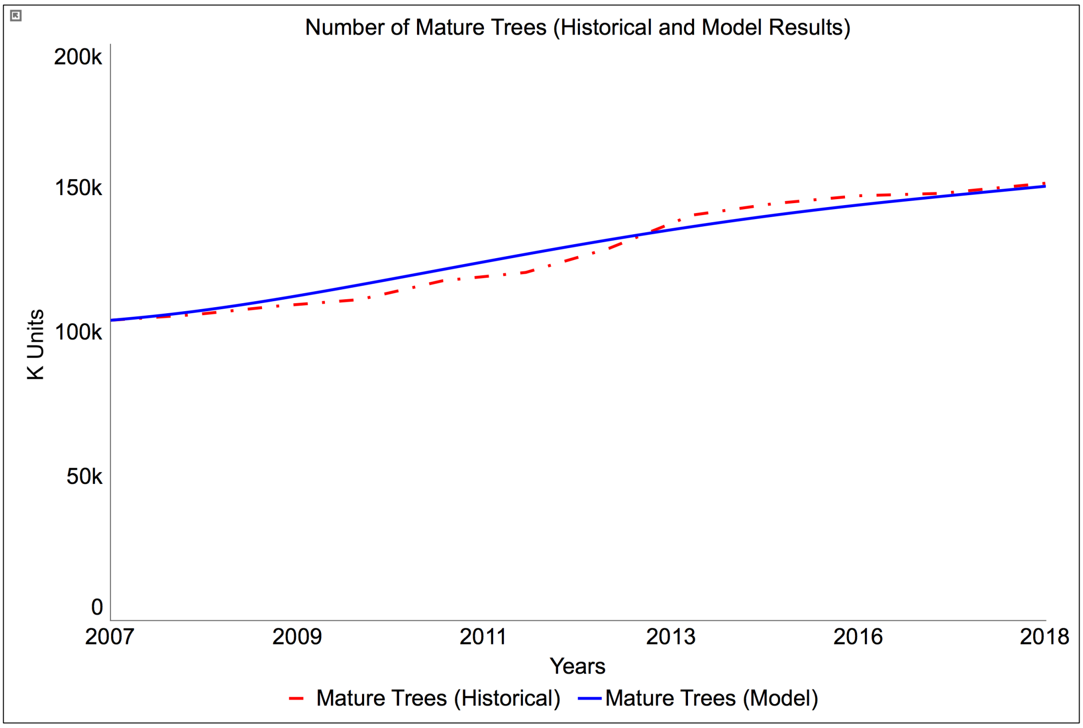

Figure 8.4: Historical Values and Model Results for Mature Trees (2007-2018)

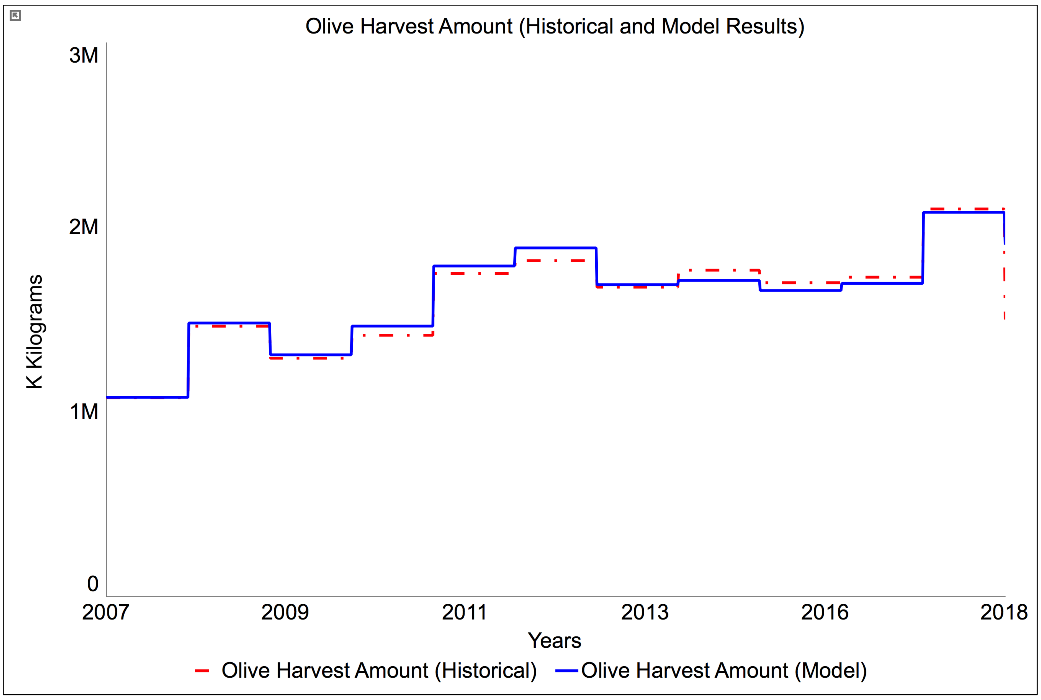

Figure 8.5: Historical Values and Model Results for Olive Fruit Harvest Amount (2007-2018)

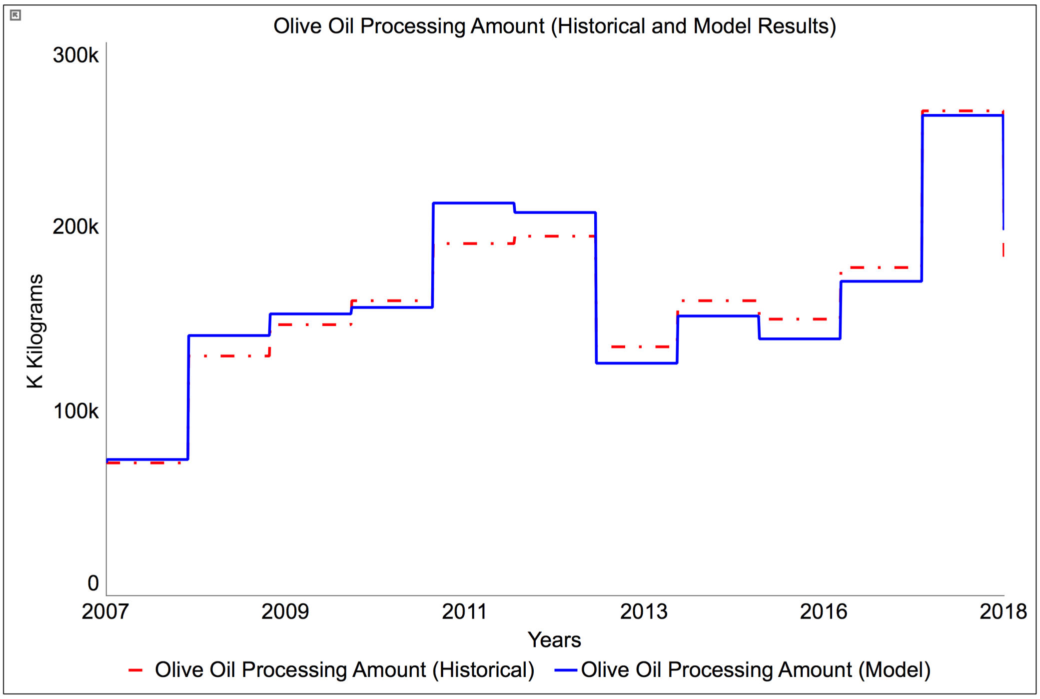

Figure 8.6: Historical Values and Model Results for Olive Oil Processing Amount (2007-2018)

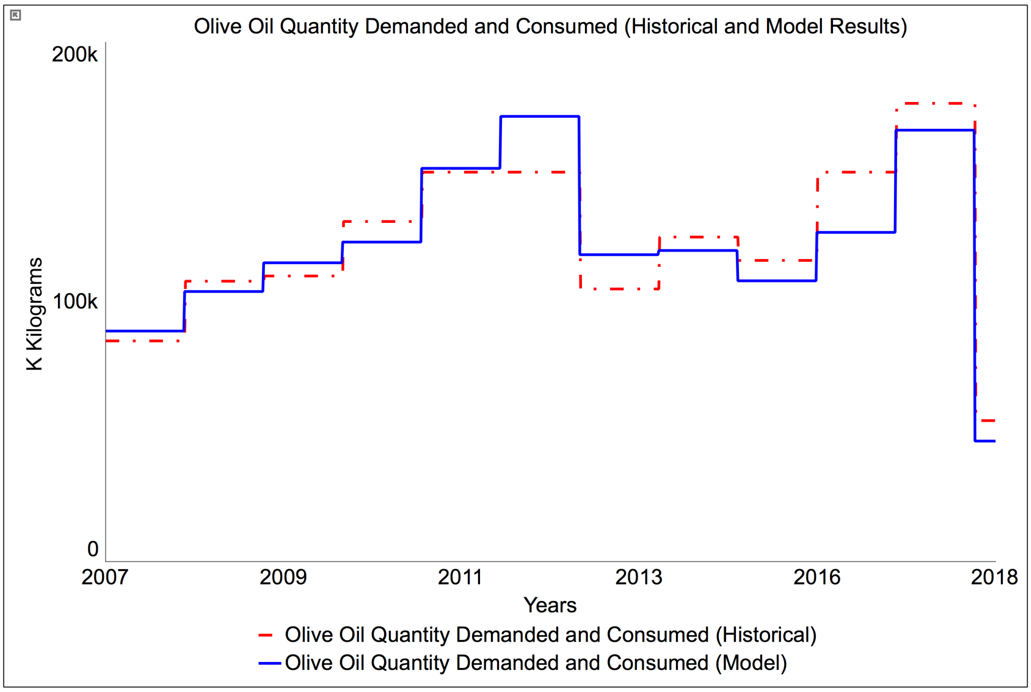

Figure 8.7: Historical Values and Model Results for Olive Oil Quantity Demanded (2007-2018)

Table 8.7: Behavior Pattern Tests: MAPE Results for Planting, Harvesting, Processing and Demand

Variable	**MAPE (2007-2018)**	**MAPE (2007-2017)**	**MAPE (2018)**
Young Trees	4.6%	4.4%	6.5%
Mature Trees	2.3%	2.5%	0.7%
Harvest Amount	4.1%	2%	27%
Processing	5.7%	5.4%	8.3%
Demand	7.2%	7.3%	5.8%

The historical and model generated annual totals of young trees and mature trees are well-matched. Harvest amount only deviates in one point, in 2018 due to the deviation in forecasted and realized value of Fruit per Mature Tree. On the other hand, model generated Olive Oil Processing Amount in 2018 is closer to its historical value despite the deviation in Olive Harvest Amount. MAPE calculations for the time periods of

2007-2018, 2007-2017 and 2018 are given in Table 8.7. Except Harvest Amount in 2018, all MAPE values are found to be below 10%.

With the aid of all structural and behavioral tests conducted, the model is found to be appropriate for its purpose in order to make policy analysis and recommendations for the olive oil value chain in Turkey.

CHAPTER 9

QUANTITATIVE POLICY AND SCENARIO ANALYSIS FOR TURKISH OLIVE OIL VALUE CHAIN

In this section, we conduct policy and scenario analysis with the purpose of proposing some improvement opportunities in Turkish olive oil value chain. For that purpose, we first construct a base model representing the reference mode in the near future, covering years 2019-2023. Then, we implement three sets of value chain improvement policies to the base model under several scenarios and discuss the performance and robustness of these policies.

9.1 Reference Mode for the Near Future: Base Run for the Years 2019-2023

As mentioned before, there are several exogenous variables in our model which consist of graphical historical data. In order to conduct quantitative policy analysis for the near future, we first need to make anticipations for these variables that consist of graphical data. For that purpose, depending on the characteristics of the historical data between 2007 and 2018, we use appropriate forecasting methods and generate a prospective data set for 2019-2023.

In forecasting, the rules of thumb described below are generally followed:

- If the historical data are stationary, then single-exponential smoothing method is used. If the data show a trend, then either a linear trend model or a double-exponential smoothing method is used. If the data show recurrent cycles or patterns, triple-exponential smoothing method is used.
- The forecasting method's smoothing coefficients are determined according to

both MAPE results they generate (which is preferably under 10%), and field information and judgment on the data set (i.e. in forecasting the export quantities in the near future, we know that trend coefficients should be much smaller than level coefficients; yet, in forecasting the market trend in the near future, trend coefficients should be closer to other coefficients, etc.).

The related variables of the modules, forecasting methods and smoothing coefficients used are given in Table 9.1, where ES stands for "Exponential Smoothing", α for level, γ for trend and δ for seasonality.

The time horizon of the model is extended to the end of year 2023. The base run results for 2019-2023 with the forecasts in Table 9.1 can be seen in Figures 9.1 and 9.2. In Figure 9.1, you can see the prices along the olive oil value chain for the complete time horizon of the model, from the end of 2007 to the end of 2023. In Figure 9.2, you can see the detailed version of the prices along the value chain from the beginning of 2019 to the end of 2023.

In policy analysis, some selected performance indicators are calculated for the period 2019-2023 and policies are compared according to these indicators. The explanations on these performance indicators are as follows:

- **Total Operation Cost:** The sum of total material, variable and fixed costs in order to perform the regarding operation for the period 2019-2023.
  - Total Growing and Harvesting Cost: It consists of Fixed Cost of Growing and Variable Cost of Harvesting which is spent for the total Olive Harvest Amount.
  - Total Cost of Olive Oil Processing: It consists of Raw Fruit Material Cost, Fixed Cost of Processing and Variable Cost of Processing for the total Processed Bulk Olive Oil.
  - Total Cost of Olive Oil Packaging: It consists of Bulk Food Material Cost, Fixed Cost of Packaging and Variable Cost of Packaging for the total Packaged Olive Oil.

Table 9.1: Graphical Variables - Information for Forecasting 2019-2023 Data

Module	**Variable**	**Forecasting Method**
Planting	Financial Supports for Planting	Single ES, $\alpha = 0.12$
Planting	Planting Costs	Linear Trend
Harvesting	Fruits per Mature Tree	Triple ES, $\alpha = 0.5$, $\gamma = 0.2$, $\delta = 0.1$
Processing	Processing Yield	Triple ES, $\alpha = 0.5$, $\gamma = 0.2$, $\delta = 0.1$
Demand	GDP per Capita	Linear Trend
Demand	Population	Linear Trend
Demand	Market Trend	Triple ES, $\alpha = 0.2$, $\gamma = 0.15$, $\delta = 0.15$
Demand	Substitute Price	Triple ES, $\alpha = 0.5$, $\gamma = 0.15$, $\delta = 0.10$
Export	Bulk Food Export Price	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.4$
Export	Packaged Food Export Price	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.4$
Export	Rate of Bulk Food Export Quantity Demanded	Triple ES, $\alpha = 0.5$, $\gamma = 0$, $\delta = 0.1$
Export	Rate of Packaged Food Export Quantity Demanded	Triple ES, $\alpha = 0.5$, $\gamma = 0$, $\delta = 0.1$
Fruit Price	Financial Aid for Growing	Single ES, $\alpha = 0.6$
Fruit Price	Reference Fixed Cost of Growing	Single ES, $\alpha = 0.11$
Fruit Price	Variable Cost of Harvesting	Double ES, $\alpha = 1$, $\gamma = 0.15$

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Table 9.1 – *Continued from previous page*

Module	**Variable**	**Forecasting Method**
Bulk Food Price	Financial Aid for Fruit Processing	Double ES, $\alpha = 0.6$, $\gamma = 1$
Bulk Food Price	Reference Fixed Cost of Processing	Single ES, $\alpha = 0.98$
Bulk Food Price	Variable Cost of Processing	Single ES, $\alpha = 0.98$
Retail Price	Reference Fixed Cost of Packaging	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.5$
Retail Price	Variable Cost of Packaging	Triple ES, $\alpha = 0.1$, $\gamma = 0.1$, $\delta = 0.5$

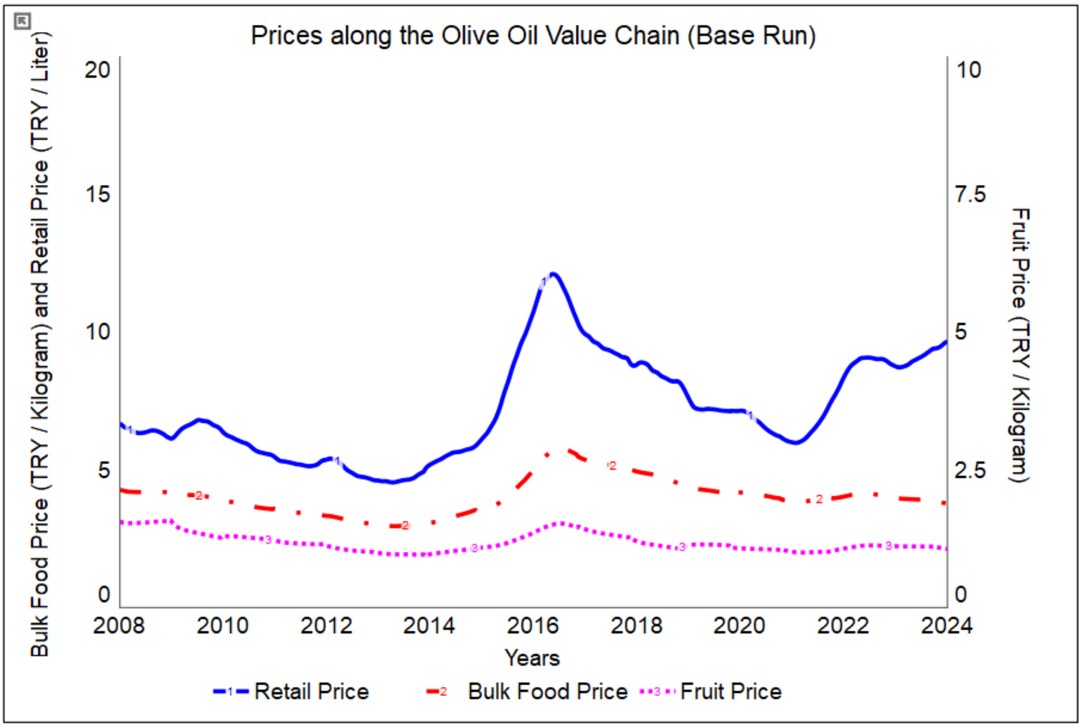

Figure 9.1: Reference Mode (Base Run) for years 2007-2023

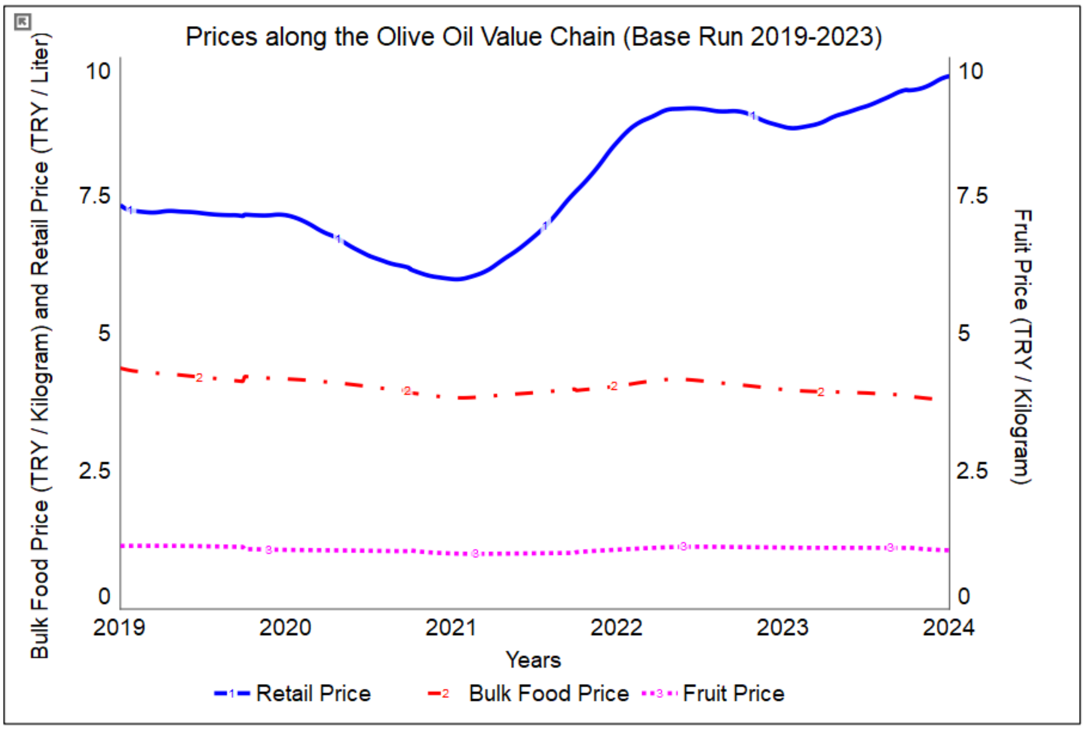

Figure 9.2: Reference Mode (Base Run) for years 2019-2023

- **Total Revenue from the Operation:** The revenue gained at the end of the regarding operation, i.e. amount of output times output price.
- **Government Expenditure for the Operation:** The total support/aid given by the government at the regarding stage.
- **Total Earning from the Operation:** Total Revenue from the Operation + Government Expenditure for the Operation - Total Operation Cost.
- **Total Value Added at the Operation:** Total Revenue from the Operation - Total Operation Cost.
- **Total Value Added Along the Chain:** Sum of Total Value Added at the Operations.

Major assumptions for these indicator calculations are listed below:

- Depending on the statistics published by FAO and TÜİK, it is assumed that the tree density in new olive orchards is approximately 32 trees/decare. This assumption is used to calculate Government Expenditure for Planting since the financial support is given based on the area of the orchard.
- Financial Support for Growing and Harvesting is given to all farmers who are registered in the Farmer Registration System.
- Depending on the field information about the olive and olive oil market, it is known that a smaller portion of farmers sell their products as “olive fruit” and rather a larger portion of farmers sell their product as “bulk olive oil”. In revenue, earning and value added calculations, it is assumed that 10% of farmers sell their products as “olive fruit” and the rest sells their product as “bulk olive oil”. As a result, calculations for the indicators in Olive Growing and Harvesting stage are conducted and presented for two distinct groups separately, as “Fruit Sellers” and “Bulk Sellers”.
- According to the statistics published by Ministry of Agriculture and Forestry, the financial support for bulk olive oil is paid for approximately half of the processed olive oil amount. This ratio is embedded to the calculations with a Financial Aid for Processing Payment Ratio of 0.5.

Table 9.2: Indicators for the Base Run during 2019-2023

Indicator	**Value (K TRY, Real)**	
Total Planting Cost		20,003
Government Expenditure for Planting		10,561
	Fruit Sell.	Bulk Sell.
Total Growing and Harvesting Cost	275,908	2,483,170
Total Revenue from Growing and Harvesting	671,077	0
Government Expenditure for Growing and Harvesting	11,811	106,300
Total Earning from Growing and Harvesting	406,981	0
Total Value Added at Growing and Harvesting	395,170	0
Total Cost of Olive Oil Processing		1,040,816
Total Revenue from Bulk Olive Oil		3,304,558
Government Expenditure for Olive Oil Processing		50,120
Total Earning from Olive Oil Processing		-63,008
Total Value Added at Olive Oil Processing		-219,428
Total Cost of Olive Oil Packaging		4,060,046
Total Revenue from Olive Oil Packaging		6,370,475
Total Earning from Olive Oil Packaging		2,310,429
Total Value Added at the Olive Oil Packaging		2,310,429
Total Value Added along the Chain		2,466,168

For the Base Run, these performance indicators are calculated as shown in Table 9.2.

In addition to the performance indicators given in Table 9.2, some comparative performance indicators are also used to compare the different policies tested against the base run:

- **Change in Social Welfare:** Depending on the modeling purpose, social welfare is sometimes used as a performance indicator in policy evaluations in system dynamics literature. For proper applications of social welfare calculations within system dynamics modeling literature, one may see He and Zang (2015) and Wang et al. (2015). Within our policy analysis context, the change in social welfare is the sum of change in consumer surplus and change in producer surplus, minus change in government expenditure.

  - **Change in Consumer Surplus:** It is shown with ΔCS_P for any policy P and formulated as in 9.1, where D_P is the quantity of demand in Policy P, RP^* is the maximum retail price that consumers are willing to pay (which is assumed to be the maximum historical retail price), RP_P is the retail price in Policy P, and subscripts for policies are 0 for Base Run and $1, 2, 3, ...$ for the policies tested.

$$\Delta CS_P = 1/2 \left(\int_{2019}^{2023} D_0(RP^* - RP_0)dt - \int_{2019}^{2023} D_P(RP^* - RP_P)dt \right) \tag{9.1}$$

  - **Change in Producer Surplus:** It is shown with ΔPS_P and formulated as in9.2, where O is the set of all operations.

$$\begin{aligned} &\Delta PS_P = \textstyle\sum_O (\text{Total Revenue from Operation}_P + \text{Government} \\ &\text{Expenditure for Operation}_P - \text{Total Cost of Operation}_P) \\ &- \textstyle\sum_O (\text{Total Revenue from Operation}_0 + \text{Government} \\ &\text{Expenditure for Operation}_0 - \text{Total Cost of Operation}_0) \end{aligned} \tag{9.2}$$

  - **Change in Government Expenditure:** It is shown with ΔGE_P and formulated as below, where O is the set of operations.

$$\begin{aligned} &\Delta GE_P = \textstyle\sum_O (\text{Government Expenditure for Operation}_P) \\ &- \textstyle\sum_O (\text{Government Expenditure for Operation}_0) \end{aligned} \tag{9.3}$$

- **Change in Social Welfare:** It is shown with ΔW_P and formulated as below.

$$\Delta W_P = \Delta CS_P + \Delta PS_P - \Delta GE_P \tag{9.4}$$

The indicators in the base run constitute the baseline for policy analysis. Now, we make policy and scenario analysis for the value chain improvement in the Turkish olive oil value chain.

9.2 Policy and Scenario Analysis

As it is presented in the previous chapters, there are several studies in literature which focus on the discontent of the stakeholders in the Turkish olive and olive oil industry and provide a set of recommendations for improvement. Within the context of economical sustainability of the stakeholders, the issues below are highlighted in many relevant studies (see Başaran (2011), Lynch and Rozema (2013), Yılmaz (2013), Apaydın et al. (2014) and Özaltaş et al. (2016)):

- Low level of productivity
- Low level of governmental financial supports
- Inability to benefit from economies of scale and hence high cost of production
- High level of agricultural input prices

These issues are interrelated by their nature and hard to be eliminated by means of immediate value chain interventions. By considering these issues, we conduct policy analysis with three sets of value chain interventions:

- **Policy 1:** Extensification of Irrigation for higher levels of productivity
- **Policy 2:** Redesign of Financial Support Policies for economical sustainability
- **Policy 3:** Empowering Cooperative Action for the benefits of economies of scale

With these three sets of value chain intervention policies, we demonstrate the functionality of our model as a policy and scenario analysis tool.

In addition to policy analysis, we aim to conduct scenario analysis simultaneously for some possible random occurrences in the near future. In the model validation step, we conduct a comprehensive behavioral sensitivity analysis to assess the sensitivity of model results to different levels of variables. Using the random components in these variables, we generate several scenarios for policy analysis and we interpret the results under these scenarios. For the sources of randomness in scenarios, the variables below are selected:

- Packaged Food Export Price
- Processing Yield

First variable is more related to "price dynamics" and the second variable is more related to "supply dynamics". Hence, we use them in different policy analysis settings.

9.2.1 Policy 1: Extensification of Irrigation

Olive orchards are known with their resistance to droughts. Yet, studies in the field show that irrigation improves the olive yield in terms of fruits per tree. Unfortunately, there are no recent official statistics on the irrigation rate in olive orchards. According to recent statistics about the irrigation in Turkey at the national level, we see that the ratio of agricultural irrigated land to total agricultural land is only 13.4% in Turkey (Trading Economics Website, 2019).

A recent study published by the International Olive Council implicitly presents the cost of irrigation and the yield in response to this irrigation cost (IOC, 2015). According to data given in this study, switching from non-irrigated treatments to irrigated treatments with approximately a 15.5% increase in unit fixed costs of olive growing, an increase of 20% in fruits per mature tree is obtained. Since the whole olive orchard land of Turkey would not be perfectly suitable for irrigation, we design the policy and change the regarding model parameters as follows:

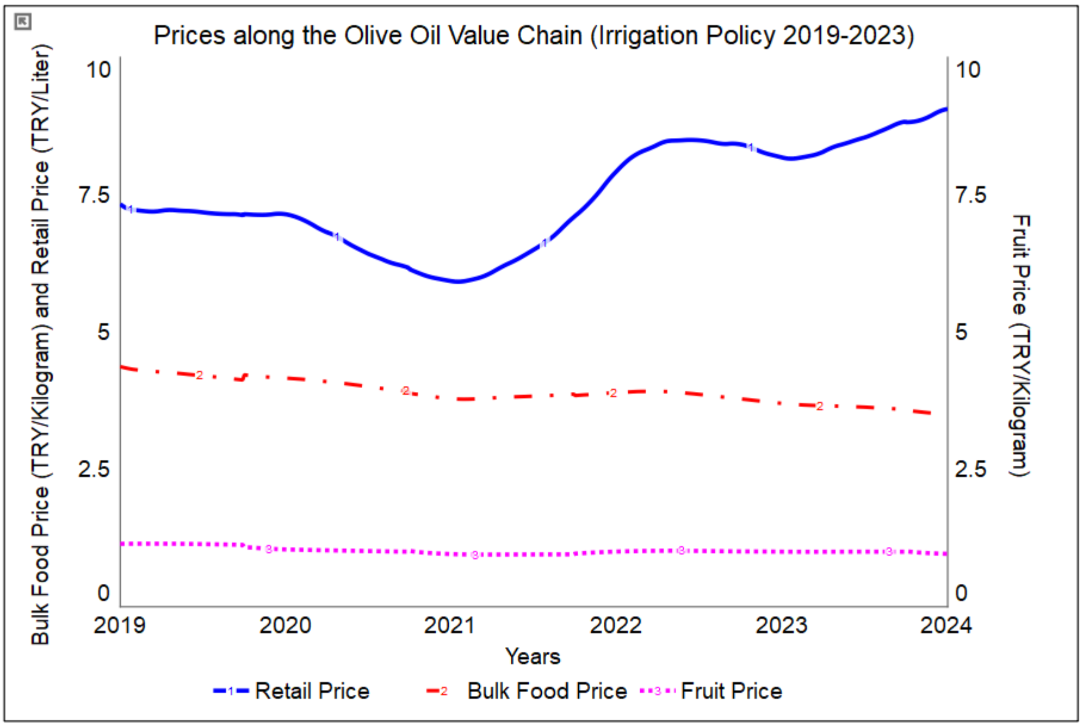

Figure 9.3: Prices along the Olive Oil Value Chain in Irrigation Policy

- Increase in Fixed Cost of Growing by 7.75% which is subsidized by the government
- Increase in Fruits per Mature Tree by 10%

The model is run with the regarding policy modifications. The performance indicators for cost, revenue, earning and value added amounts can be found in Table 9.3. The prices along the olive oil value chain in the policy can be seen in Figure 9.3. The comparative graphs for Fruit, Bulk Food and Retail Prices are in Figures 9.4, 9.5 and 9.6, respectively. The comparative graphs for consumer surplus, producer surplus, government expenditure and social wealth in a cumulative manner are given in Figure 9.7.

The implications gathered from Table 9.3 and Figures 9.3, 9.4, 9.5, 9.6 and 9.7 can be summarized as follows:

- Under the extensification of irrigation policy, both consumer surplus and producer surplus improve due to increasing yield. Social wealth also improves

Table 9.3: Indicators for the Irrigation Policy during 2019-2023

Indicator	**Value (K TRY)**		
Total Planting Cost	17,113		$\Downarrow$
Government Expenditure for Planting	9,041		$\Downarrow$
	Fruit Sell.	Bulk Sell.	
Total Growing and Harvesting Cost	323,396	2,910,566	$\Uparrow$
Total Revenue from Growing and Harvesting	707,204	0	$\Uparrow$
Government Expenditure for Growing and Harvest.	24,798	223,185	$\Uparrow$
Total Earning from Growing and Harvesting	408,606	0	$\Uparrow$
Total Value Added at Growing and Harvesting	383,808	0	$\Downarrow$
Total Cost of Olive Oil Processing	1,122,108		$\Uparrow$
Total Revenue from Bulk Olive Oil	3,543,741		$\Uparrow$
Government Expenditure for Olive Oil Processing	56,672		$\Uparrow$
Total Earning from Olive Oil Processing	-209,076		$\Downarrow$
Total Value Added at Olive Oil Processing	-488,933		$\Downarrow$
Total Cost of Olive Oil Packaging	4,392,877		$\Uparrow$
Total Revenue from Olive Oil Packaging	6,848,747		$\Uparrow$
Total Earning from Olive Oil Packaging	2,455,870		$\Uparrow$
Total Value Added at Olive Oil Packaging	2,455,870		$\Uparrow$
Total Value Added along the Chain	2,333,631		$\Downarrow$
ΔCS_P	236,171		$\Uparrow$
ΔPS_P	2,367		$\Uparrow$
ΔGE_P	134,904		$\Uparrow$
ΔW_P	103,633		$\Uparrow$

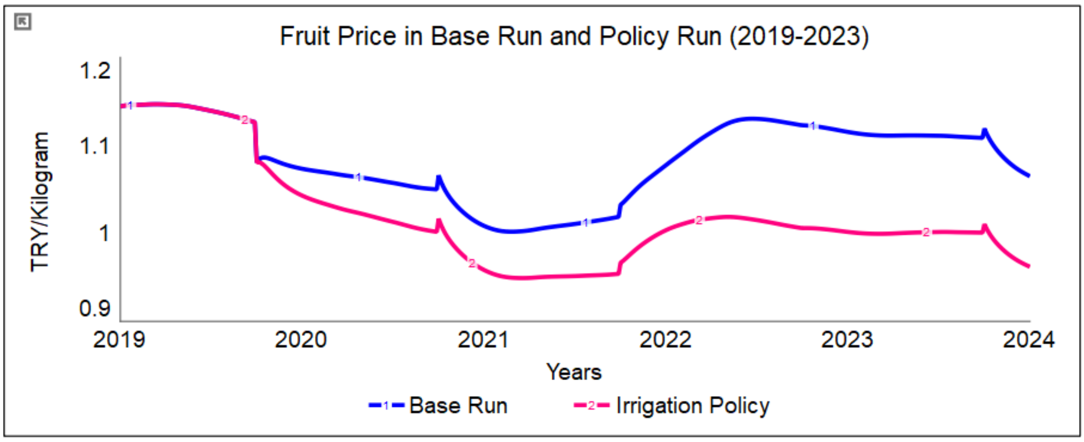

Figure 9.4: Fruit Price: Base Run and Irrigation Policy Run

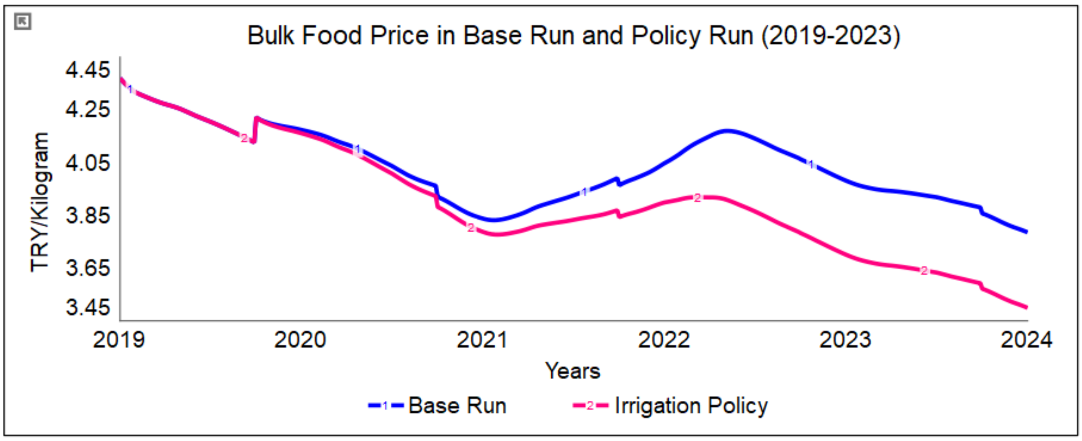

Figure 9.5: Bulk Food Price: Base Run and Irrigation Policy Run

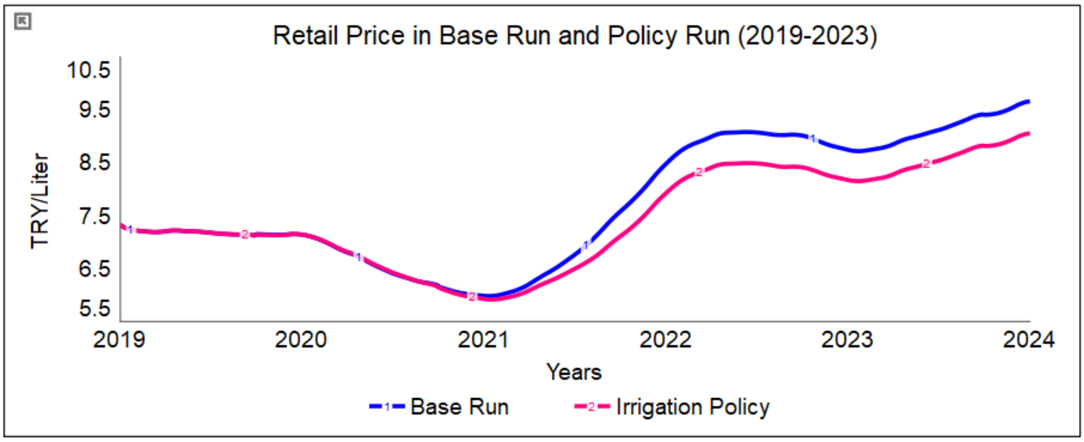

Figure 9.6: Retail Price: Base Run and Irrigation Policy Run

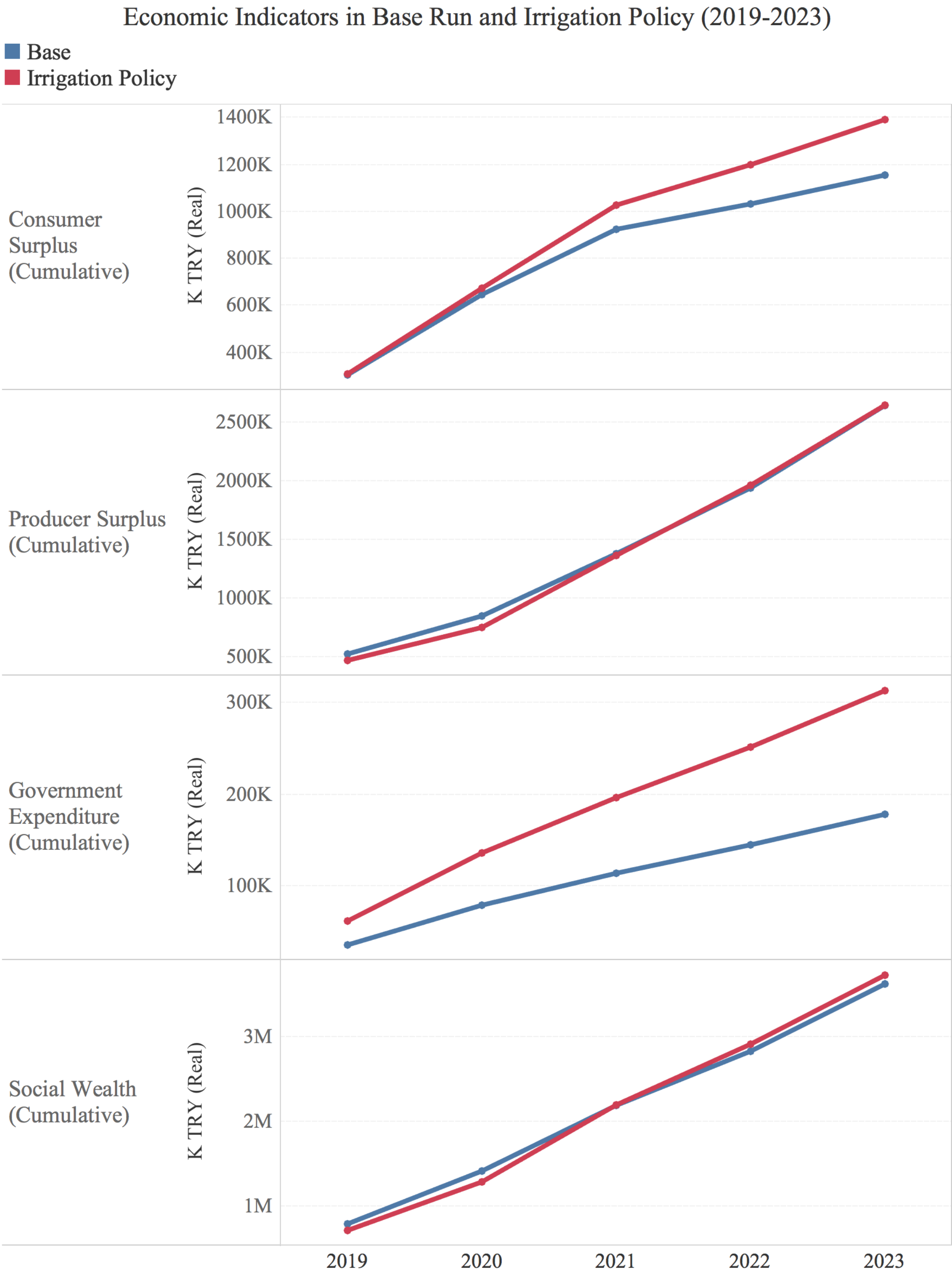

Figure 9.7: Economic Indicators: Base Run and Irrigation Policy Run

despite the increasing Government Expenditure. Additionally, all three price levels drop well below their Base Run results.

- Total Value Added along the Chain has slightly decreased since the cost of operations has increased and the increase in Fixed Cost of Growing is subsidized by the government.

- Total Planting Cost and Government Expenditure for Planting have decreased since productivity per tree has increased and hence the desired tree stock has slightly decreased.

- All economic indicators (except Total Value Added) about Growing and Harvesting have increased since the volume of the regarding operations have also increased. The reason behind the decreasing Total Value Added at Growing and Harvesting is the increased Fixed Cost of Growing for irrigation.

- Earnings in Growing, Harvesting and Packaging stages improve by means of the proposed policy. On the other hand, due to lower levels of Bulk Food Prices with increasing bulk food supply, Total Earning and Value Added in Olive Oil Processing drop below their Base Run Results.

- The players at the end of the chain, both the retailers and the consumers, benefit most from this policy, especially when the total surpluses between 2019-2023 are considered.

After the base run and initial policy run results are compared, we then conduct the policy analysis under several scenarios about Packaged Export Price. Since it is an exogenous and graphical variable, we have used appropriate forecasting methods to determine its values for 2019-2023. The triple exponential smoothing method in forecasting has provided residuals with a mean of 0 and standard deviation of 0.438. With this value, we add a random variable to the model which generates the random residual portion of Packaged Food Export Price. Different values of Packaged Food Export Price naturally generate different results for prices and economical indicators along the value chain. For demonstrative purposes, we present four additional run results with random Packaged Olive Oil Export Price. The export price values are

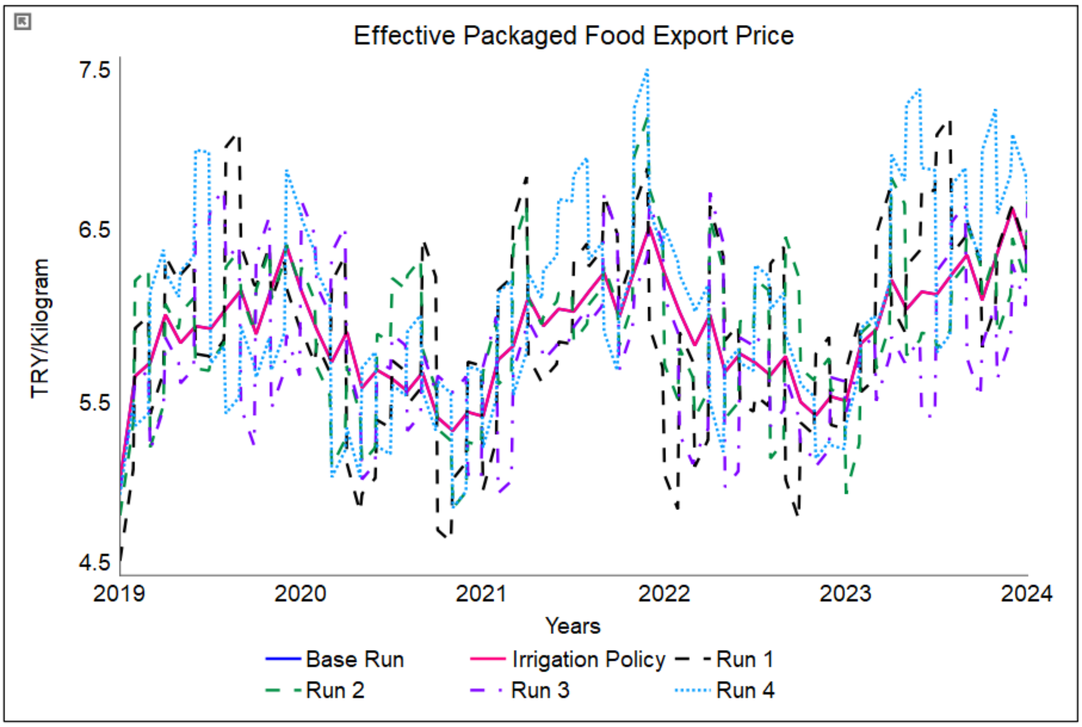

Figure 9.8: Different Packaged Food Export Price Values

shown in Figure 9.8 and the resulting price levels can be seen in Figures 9.9, 9.10 and 9.11.

When we investigate Figures 9.9, 9.10 and 9.11, the dynamics of the policy under different Packaged Olive Oil Price scenarios can be interpreted as follows:

- Retail Price is the most sensitive and fruit price is the most robust price level when exposed to random Packaged Olive Oil Export Prices.
- Fruit Price and Bulk Food Price follow the similar behavior under uncertainty; even if Packaged Olive Oil Export Prices are random, Fruit Prices and Bulk Food Prices drop well below Base Run levels in 2019-2023.
- If Packaged Food Export Prices happen to be high (Run 4), Retail Prices may go well above the Base Run results. High export prices increase the retail price, hence affect the retailers and the consumers the most.
- If the aim of the decision maker is to increase the earnings of the farmers in Growing and Harvesting stage, this policy gives robust results in terms of im-

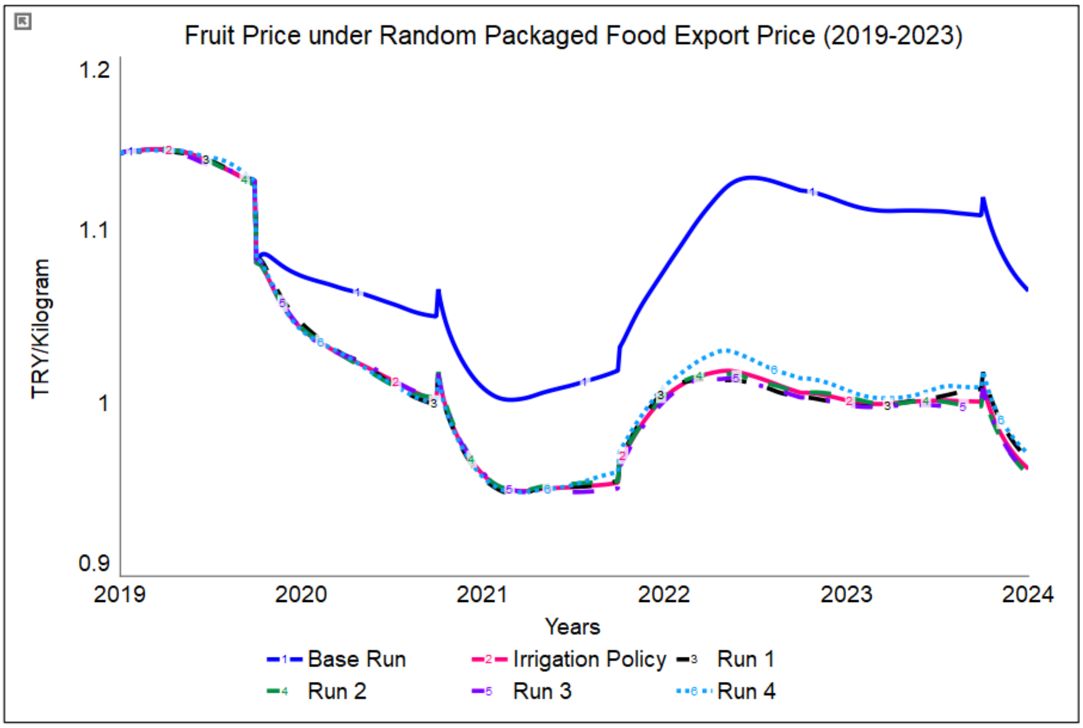

Figure 9.9: Fruit Price under Different Scenarios of Packaged Food Export Prices

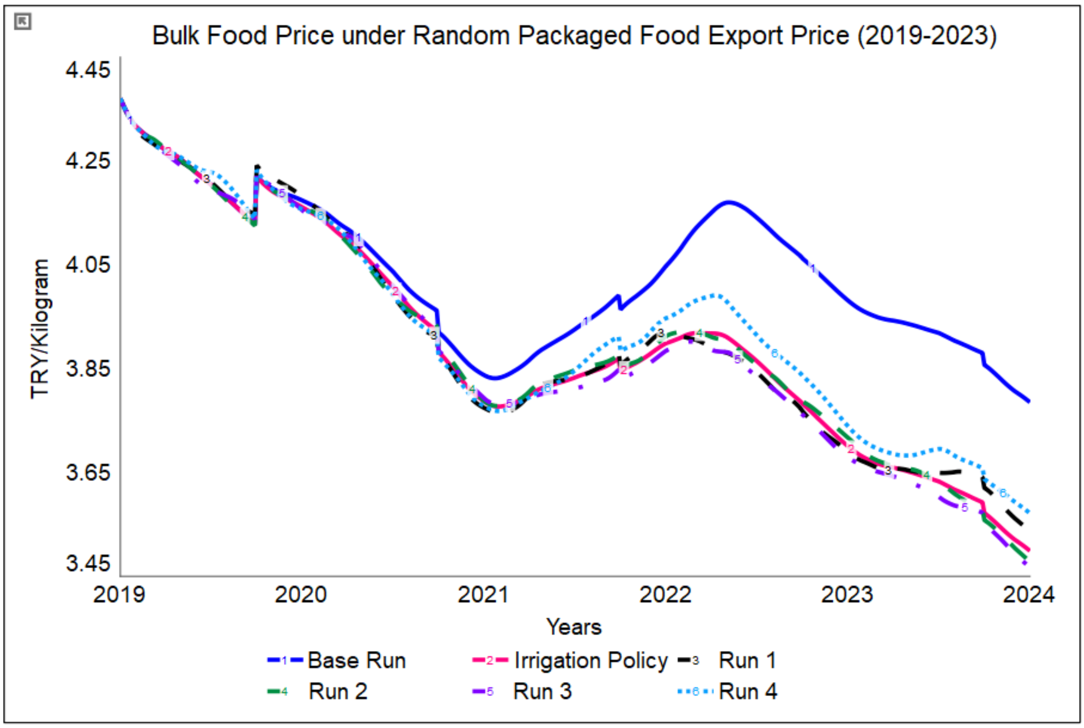

Figure 9.10: Bulk Food Price under Different Scenarios of Packaged Food Export Prices

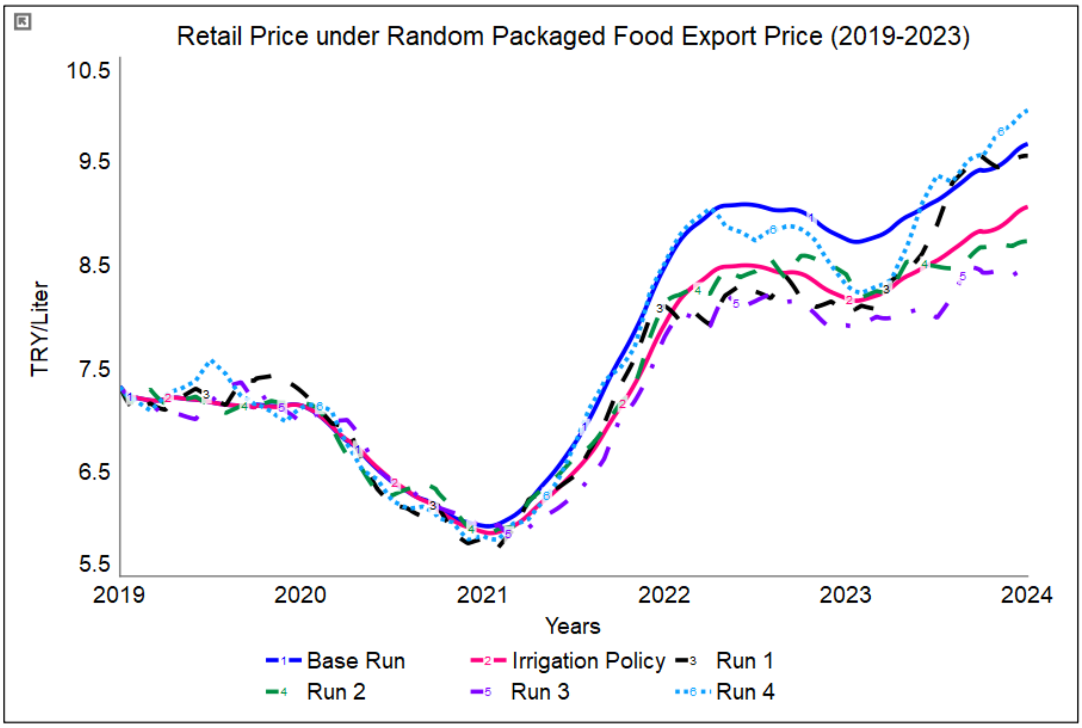

Figure 9.11: Retail Price under Different Scenarios of Packaged Food Export Prices

provement. Yet, this policy is prone to end in losses in consumer surplus, if Packaged Food Export Price is expected to have high level of randomness.

9.2.2 Policy Set 2: Redesign of Financial Support Policies

In the reports and literature published on improvement areas of Turkish olive oil, stakeholders emphasize the necessity for the redesign of the financial support schemes. With this motivation, we analyze different financial support schemes and question their robustness under different scenarios.

For financial aids, two candidate policy solutions can be offered. First one is a new financial aid in harvesting stage. In several reports, the stakeholders suggest that additional financial aids be paid for each kg of olives harvested. Additionally, during the behavior sensitivity analysis, we observe that, the whole chain dynamics is very sensitive to Variable Cost of Harvesting. Hence, a policy to decrease the effect of Variable Cost of Harvesting could help the stakeholders in that stage.

Another financial aid solution can be increasing the financial aid given in Processing stage. Since we observe that olive oil processing stage operates with negative earnings (i.e. revenue - cost + financial aids is still negative). So, we should look for a solution to make the stakeholders to better off in Processing stage.

As the source of randomness in scenario analysis, we try both of these policies and question their robustness under different olive oil processing yield conditions.

Since olive oil processing yield is an exogenous and graphical variable, we use forecasting to determine its values in 2019-2023. The triple exponential smoothing method for forecasting have provided residuals with a mean of 0 and standard deviation of 0.02, based on which we add a random variable to the model in order to generate the random portion of the olive oil processing yield. Different values of oil yield naturally generate different results for prices and economical indicators along the value chain. In the following subsection, we investigate the results and robustness of these policy implementations.

9.2.2.1 Policy 2.1: Financial Aid for Harvesting

As a new financial policy instrument, we analyze the policy of paying 0.021 TRY/Kg for the output of harvesting operations. This amount covers approximately 10% of the variable cost of harvesting operations. Before conducting any random analysis, we investigate what this policy brings about when compared to the base run results. The performance indicators for cost, revenue, earnings and value added amounts can be found in Table 9.4.

One can see an overview of prices along the value chain under Financial Aid for Harvesting Policy in Figure 9.12, and comparison of prices with the Base Run results in Figures 9.13, 9.14 and 9.15. The comparative graphs for consumer surplus, producer surplus, government expenditure and social wealth are given in a cumulative manner in Figure 9.16.

The major observations gathered from Table 9.4 and Figures 9.12, 9.13, 9.14, 9.15 and 9.16 are as follows:

Table 9.4: Indicators for the Financial Aid for Harvesting Policy during 2019-2023

Indicator	**Value (K TRY)**		
Total Planting Cost		19,815	⇓
Government Expenditure for Planting		10,468	⇓
	Fruit Sell.	Bulk Sell.	
Total Growing and Harvesting Cost	275,668	2,481,010	⇓
Total Revenue from Growing and Harvesting	643,233	0	⇓
Government Expenditure for Growing and Harvest.	24,923	224,303	⇑
Total Earning from Growing and Harvesting	392,488	0	⇓
Total Value Added at Growing and Harvesting	367,565	0	⇓
Total Cost of Olive Oil Processing		1,012,935	⇓
Total Revenue from Bulk Olive Oil		3,277,792	⇓
Government Expenditure for Olive Oil Processing		50,087	⇓
Total Earning from Olive Oil Processing		58,236	⇑
Total Value Added at Olive Oil Processing		-216,153	⇑
Total Cost of Olive Oil Packaging		4,032,689	⇓
Total Revenue from Olive Oil Packaging		6,338,482	⇓
Total Earning from Olive Oil Packaging		2,305,794	⇓
Total Value Added at Olive Oil Packaging		2,305,794	⇓
Total Value Added along the Chain		2,437,390	⇓
ΔCS_P		12,267	⇑
ΔPS_P		102,210	⇑
ΔGE_P		130,988	⇑
ΔW_P		-16,511	⇓

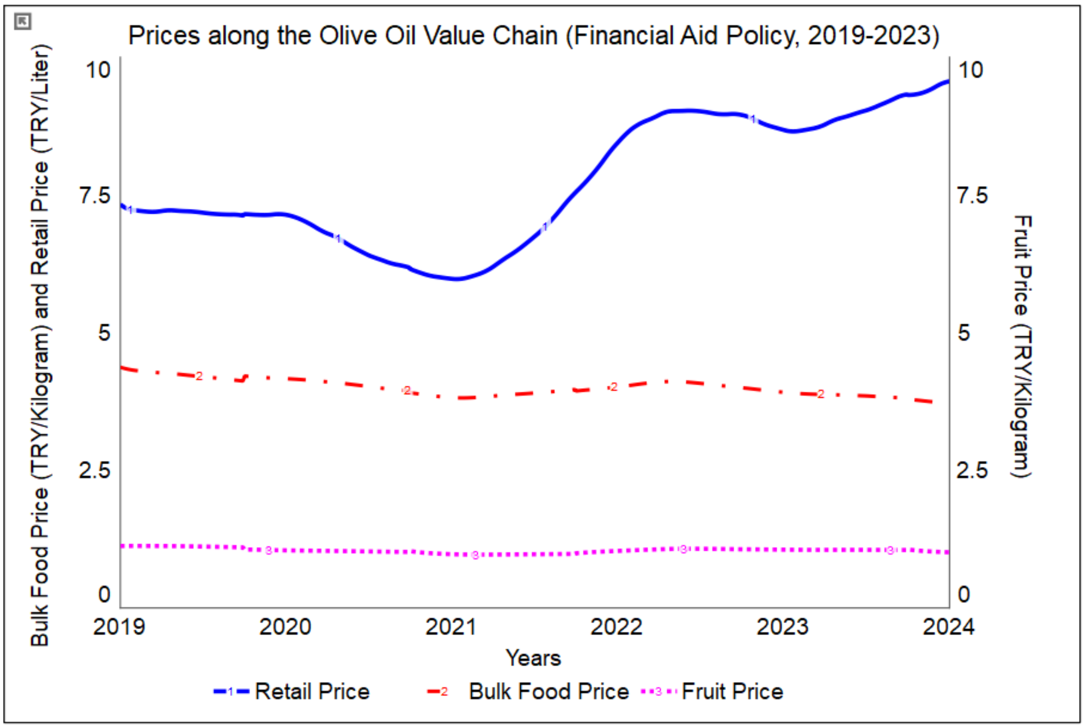

Figure 9.12: Prices along the Olive Oil Value Chain in Financial Aid for Harvesting Policy

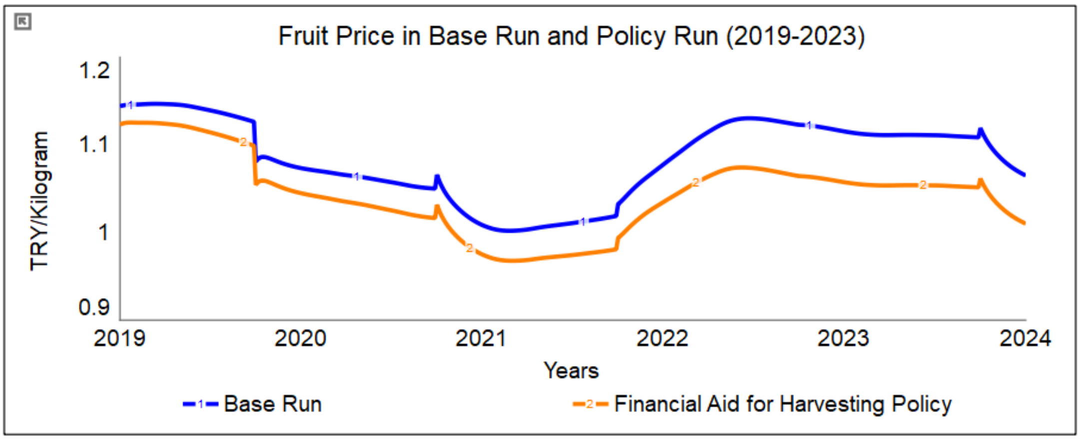

Figure 9.13: Fruit Price: Base Run and Financial Aid for Harvesting Policy Run

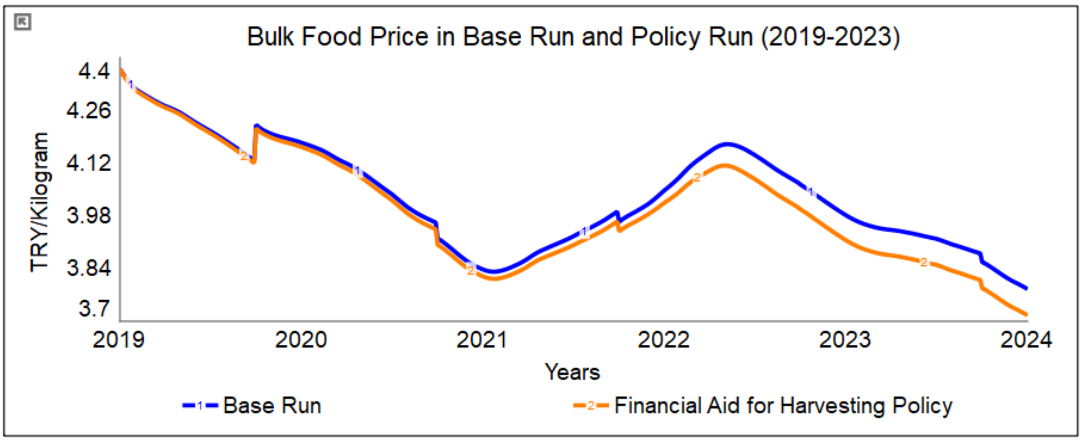

Figure 9.14: Bulk Food Price: Base Run and Financial Aid for Harvesting Policy Run

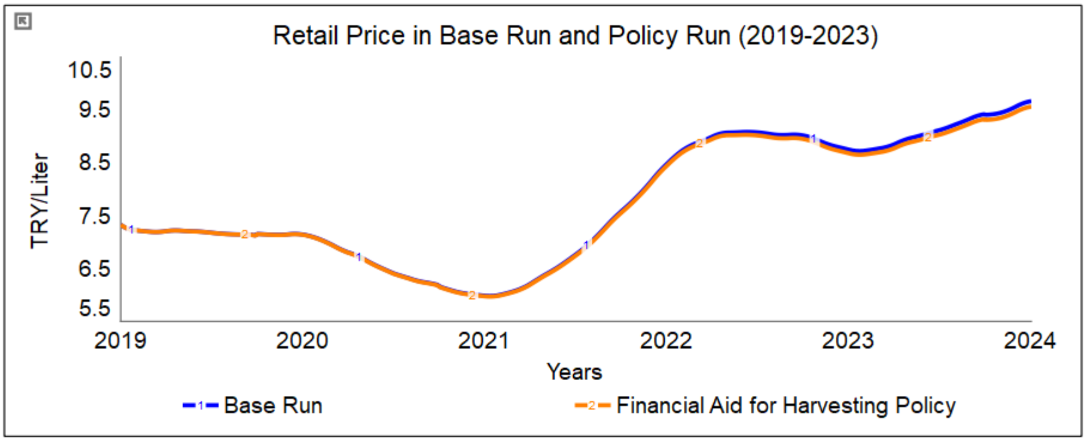

Figure 9.15: Retail Price: Base Run and Financial Aid for Harvesting Policy Run

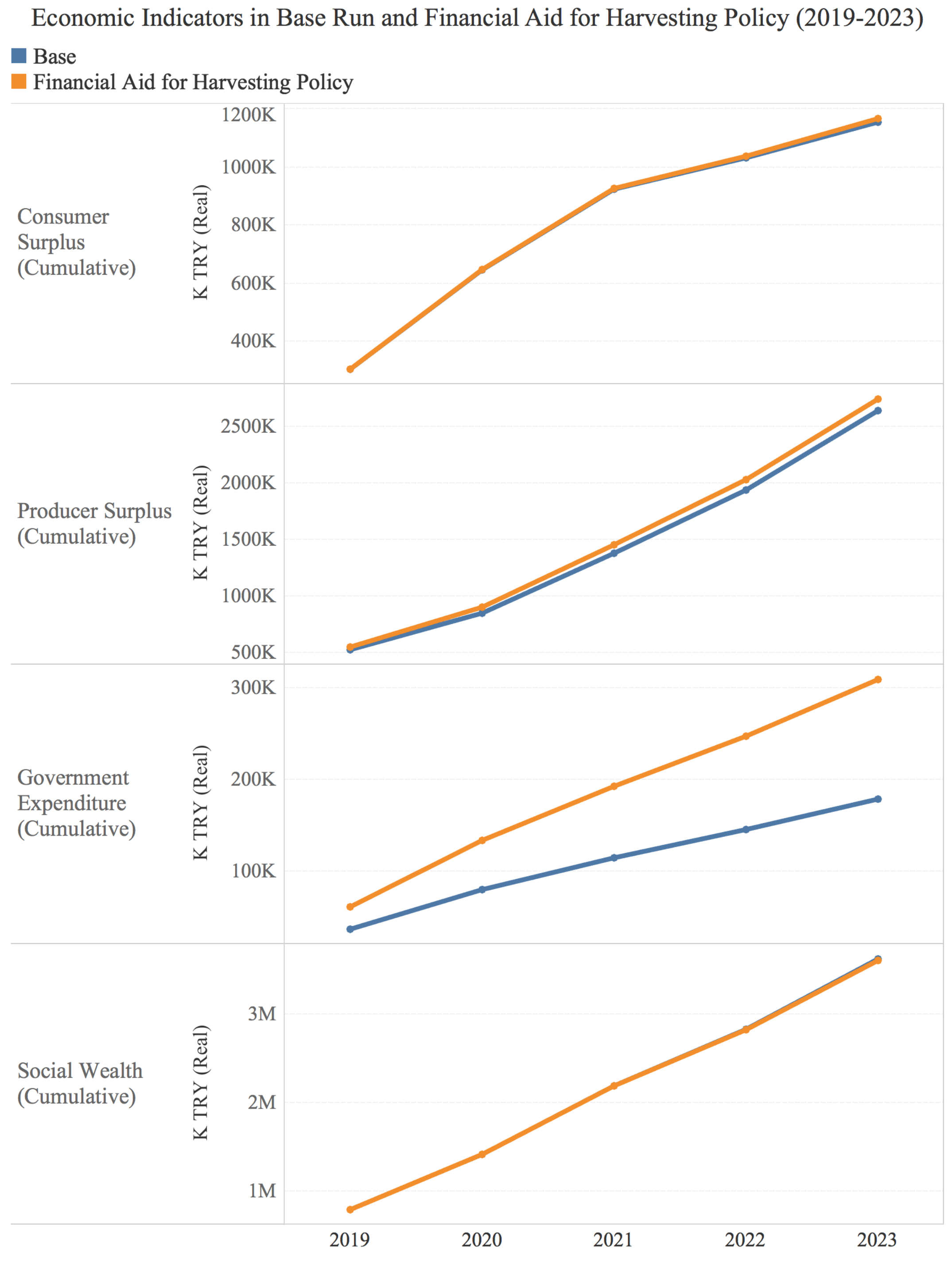

Figure 9.16: Economic Indicators: Base Run and Financial Aid for Harvesting Policy Run

- All three price levels consistently fall below the base run prices.
- Fruit price is the most sensitive price to the policy parameters.
- The idea of the policy is that, with the financial aid in the harvesting process, the stakeholders selling fruits have the will to sell the fruits in a cheaper way, since they obtain one portion of their earnings from financial aids. Hence, in the following stages, processing and packaging, the relevant stakeholders are able to buy raw material in a cheaper way.
- The good thing about this policy is that, along the whole chain, prices are below the Base Run level and unit profitability of both processing and packaging is above the Base Run level, which indicate that stakeholders in these stages are willing to produce more and consumers are willing to consume more in a cheaper way, ultimately leading to a growth in the whole industry.
- One prominent observation with this policy is the significant improvement in the producer surplus. Similar to Irrigation Policy, both the consumer surplus and the producer surplus are improved with Financial Aid for Harvesting Policy. Yet, the government expenditure is higher with this policy, which results in a slight decrease in social wealth.
- When the net change in government expenditure is considered, the budget in Irrigation Policy is very similar to the budget in Financial Aid for Harvesting Policy. Yet, the former policy results in a net positive change whereas the latter results in a net negative change in social wealth.
- Total Earnings from Growing, Harvesting and Packaging stages only slightly differ from the Base Run results. On the other hand, Total Earning and Value Added amounts in Processing stage are significantly improved. Relatively, the winner of this policy is the stakeholders in the olive oil processing stage.

Now, we make the Processing Yield random, and conduct several random runs. For demonstrative purposes, we present four additional run results in Figures 9.18, 9.19 and 9.20 for the olive oil yield values given in Figure 9.17.

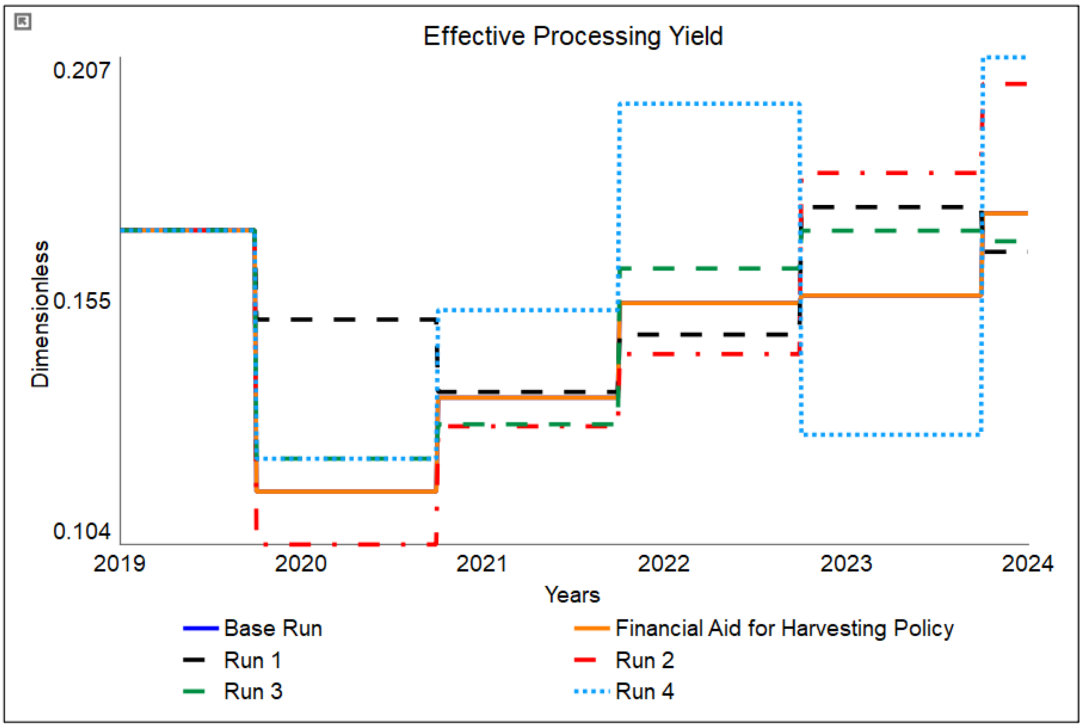

Figure 9.17: Different Processing Yield Values in Financial Aid for Harvesting Policy

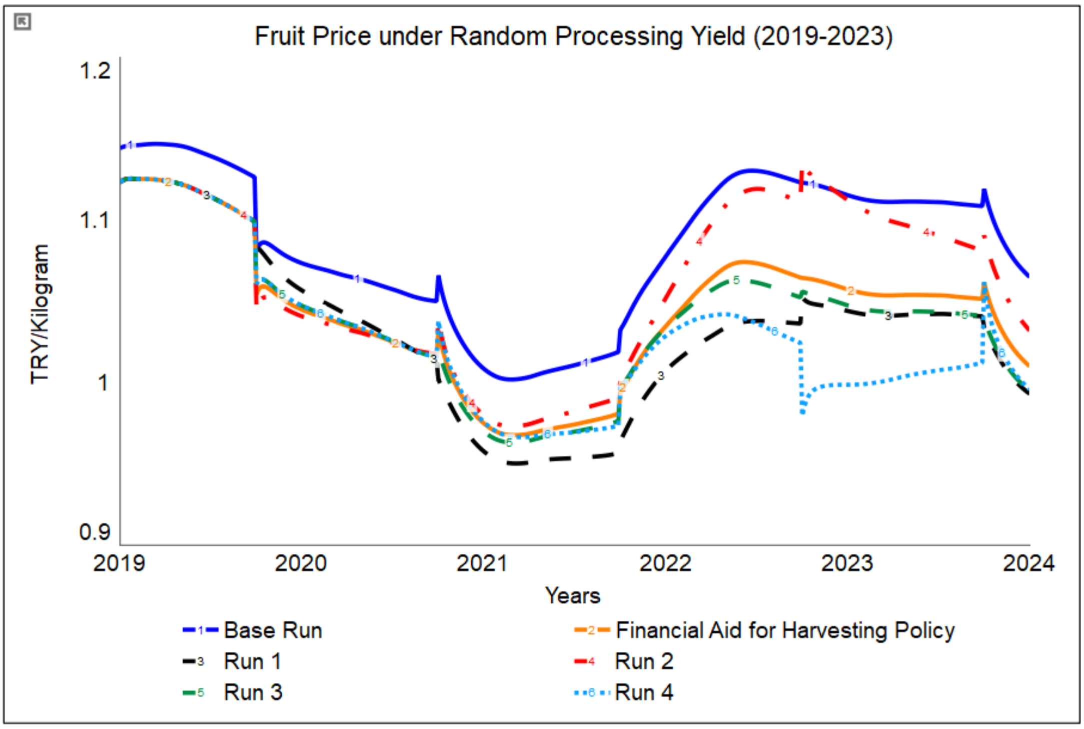

Figure 9.18: Fruit Price in Financial Aid for Harvesting Policy under Different Scenarios of Processing Yield

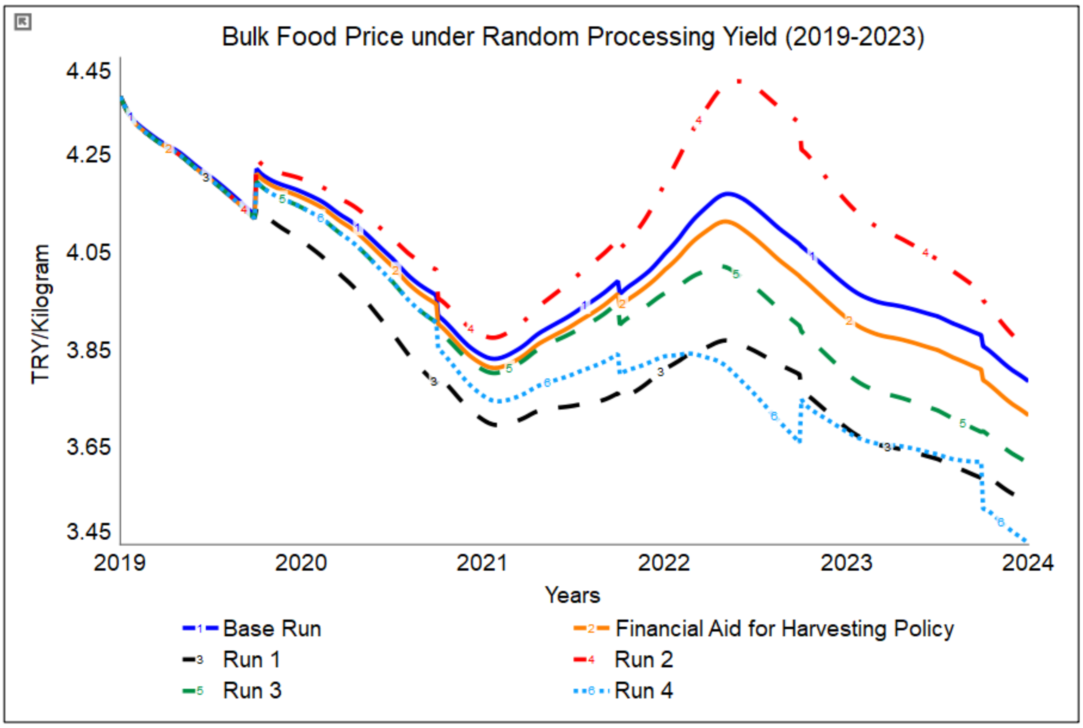

Figure 9.19: Bulk Food Price in Financial Aid for Harvesting Policy under Different Scenarios of Processing Yield

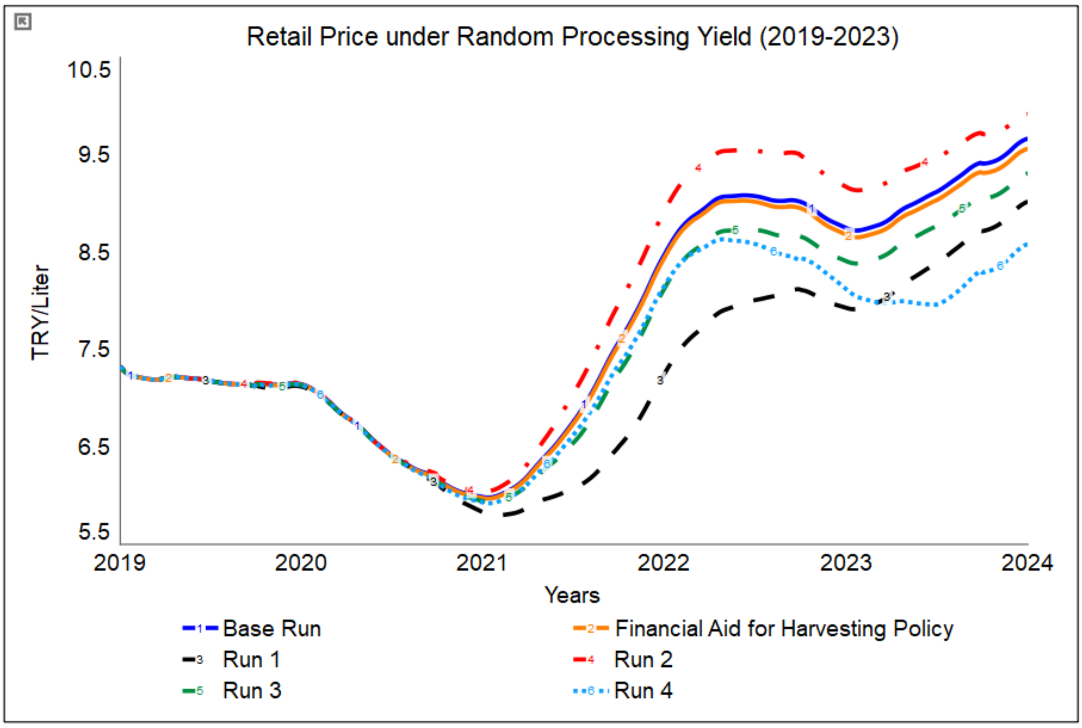

Figure 9.20: Retail Price in Financial Aid for Harvesting Policy under Different Scenarios of Processing Yield

The major observations gathered from random run results are given below:

- All three price levels are found to be sensitive to Processing Yield.
- When Processing Yield turns out to be worse than expected for some consecutive years (see Run 2 until 2022-2023 season), Fruit Price is observed to be lying below the Base Run results up to a certain point (at the beginning of 2023), whereas Bulk Food Price and Retail Price consistently lie above the Base Run results through the whole time horizon. The reason is that Processing Yield directly affect the available supply of bulk food and packaged food.
- When a worse (better) year is followed by a better (worse) year in terms of Processing Yield (see Run 2 and Run 4 for years 2021-2022 and 2022-2023), prices exhibit harsh turns in their behavioral directions (especially, see Figure 9.18 for Fruit Price). The reasons behind these behaviors are the unexpected changes in supply and demand ratio and the effects among different price levels.
- When the mean absolute percent deviation from the expected behavior of the price is considered, the most sensitive stage to Processing Yield is observed to be Processing.

9.2.2.2 Policy 2.2: Financial Aid Improvement for Processing

Since the only stage operating with "negative" earnings in the Base Run is the Processing, we also make policy analysis of financial aid improvement in processing. In the previous policy, the government expenditure in Harvesting has increased approximately by 130,000 K TRY for five years. Now, in this policy, we inquire the question: what if this amount is invested in processing operations rather than harvesting operations?

In Figure 9.21, we can see an overview of prices along the value chain under Financial Aid Improvement for Processing Policy and comparison of prices with the Base Run results in Figures 9.22, 9.23 and 9.24. The performance indicators for cost, revenue, earnings and value added amounts can be found in Table 9.5. The comparative graphs for consumer surplus, producer surplus, government expenditure and social wealth

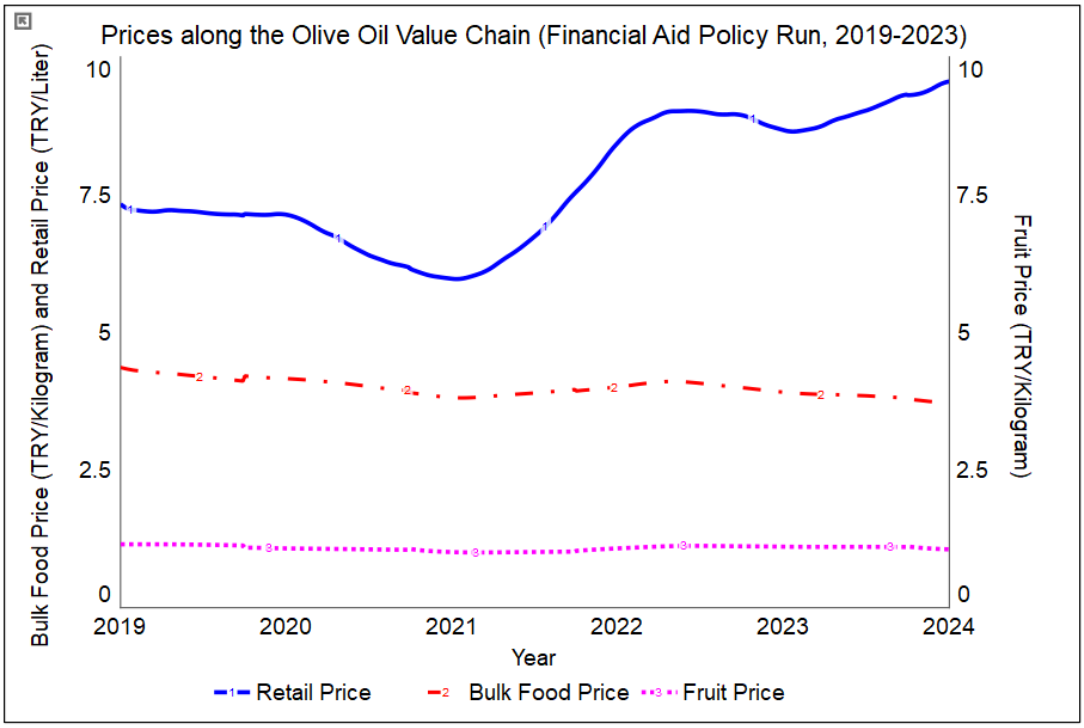

Figure 9.21: Prices along the Value Chain in Financial Aid Improvement for Processing Policy

are given in a cumulative manner in Figure 9.25.

The major observations gathered from Table 9.5 and Figures 9.22, 9.23, 9.24 and 9.25 are as follows:

- All three price levels fall below the Base Run prices (except a slight increase of Fruit Price in the first year).
- Bulk food price is the most sensitive price to the regarding policy parameters.
- Both bulk food price and retail price lie below their base run results since the beginning of the time horizon of the policy. Hence, Cost of Olive Oil Packaging turns out to be less than its base level due to lower bulk food price as the material cost of packaging. Additionally, customers benefit from lower prices and consumer surplus turns out to be positive.
- Unit profitability of both processing and packaging operations increases with respect to base run results. This indicates that governmental expenditure serves

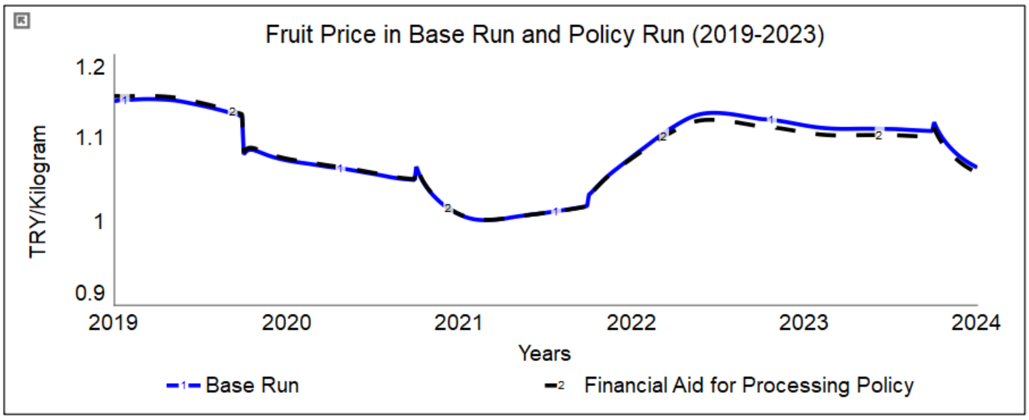

Figure 9.22: Fruit Price: Base Run and Financial Aid Improvement for Processing Policy Run

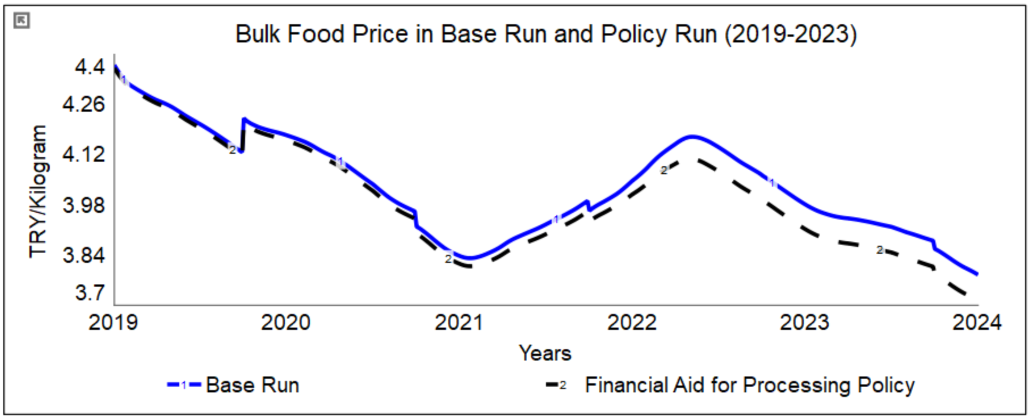

Figure 9.23: Bulk Food Price: Base Run and Financial Aid Improvement for Processing Policy Run

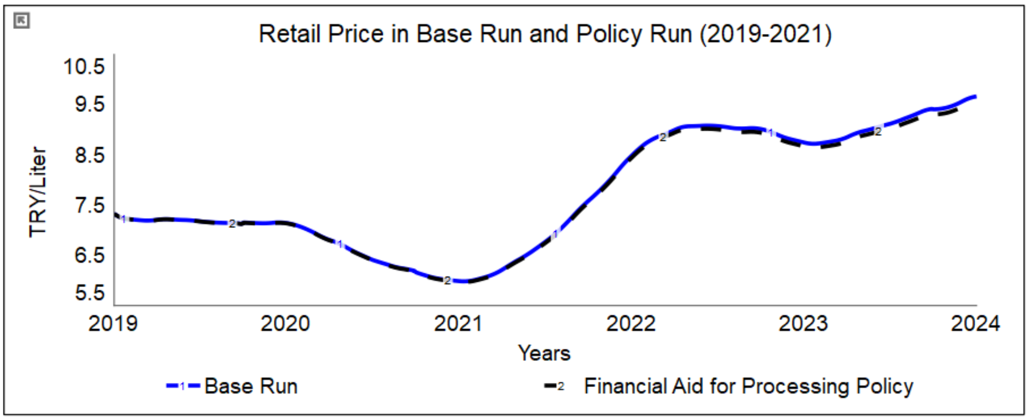

Figure 9.24: Retail Price: Base Run and Financial Aid Improvement for Processing Policy Run

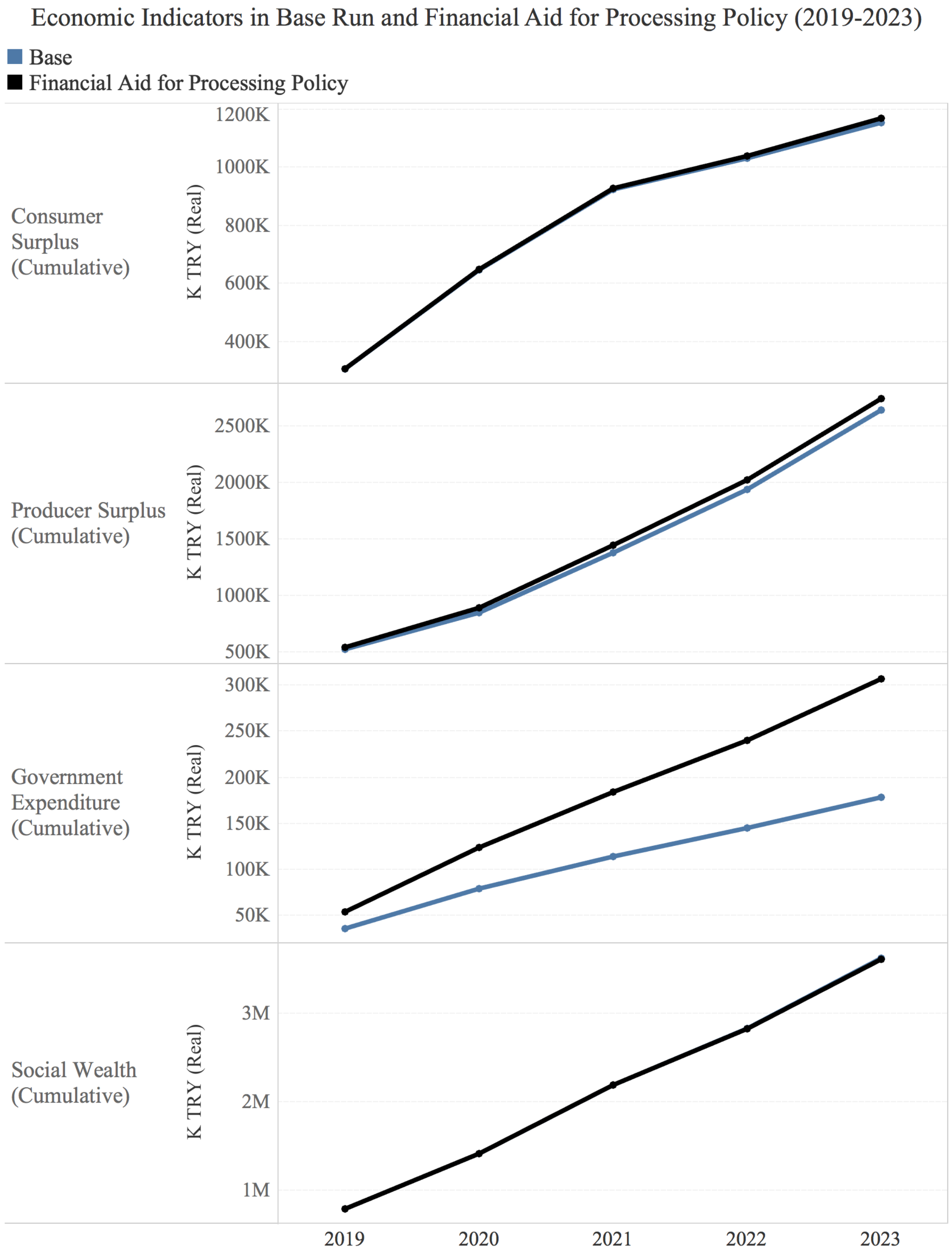

Figure 9.25: Economic Indicators: Base Run and Financial Aid Improvement for Processing Policy Run

Table 9.5: Indicators for the Financial Aid Improvement for Processing Policy during 2019-2023

Indicator	**Value (K TRY)**		
Total Planting Cost	19,963		$\Downarrow$
Government Expenditure for Planting	10,542		$\Downarrow$
	Fruit Sell.	Bulk Sell.	
Total Growing and Harvesting Cost	275,866	2,482,790	$\Downarrow$
Total Revenue from Growing and Harvesting	669,287	0	$\Downarrow$
Government Expenditure for Growing and Harvest.	11,810	106,294	$\Downarrow$
Total Earning from Growing and Harvesting	405,232	0	$\Downarrow$
Total Value Added at Growing and Harvesting	393,421	0	$\Downarrow$
Total Cost of Olive Oil Processing	1,039,536		$\Downarrow$
Total Revenue from Bulk Olive Oil	3,279,177		$\Downarrow$
Government Expenditure for Olive Oil Processing	178,652		$\Uparrow$
Total Earning from Olive Oil Processing	41,796		$\Uparrow$
Total Value Added at Olive Oil Processing	-243,150		$\Downarrow$
Total Cost of Olive Oil Packaging	4,035,137		$\Downarrow$
Total Revenue from Olive Oil Packaging	6,343,612		$\Downarrow$
Total Earning from Olive Oil Packaging	2,308,475		$\Downarrow$
Total Value Added at Olive Oil Packaging	2,308,475		$\Downarrow$
Total Value Added along the Chain	2,438,784		$\Downarrow$
ΔCS_P	15,257		$\Uparrow$
ΔPS_P	101,121		$\Uparrow$
ΔGE_P	128,506		$\Uparrow$
ΔW_P	-12,128		$\Downarrow$

for the purpose of the economical sustainability of the stakeholders in the regarding operations.

- Similar to previous policies considered, both the consumer surplus and the producer surplus are improved in Financial Aid Improvement for Processing Policy. Yet, as a result of the high level of governmental expenditure, change in social welfare turns out to be negative.

- Again, similar to other financial aid policy, Total Earnings from Growing, Harvesting and Packaging stages only slightly differ from the Base Run results. On the other hand, Total Earning in Processing stage has significantly improved. Relatively, the winner of this policy is again the stakeholders in the olive oil processing stage.

- When we compare the two financial aid policies, Financial Aid for Harvesting and Financial Aid Improvement for Processing, their budget is very similar in terms of change in government expenditure, yet, the latter policy is superior to the former in terms of the change in social wealth.

Now, similar to the previous financial aid policy analysis, we make the Processing Yield random, and conduct several random runs. For demonstrative purposes, we present four additional run results in Figures 9.27, 9.28 and 9.29 for the olive oil yield values given in Figure 9.26.

The major observations gathered from random run results are generally similar to the observations gathered from the random run results in Financial Aid for Harvesting Policy. These observations are summarized below:

- Similar to Financial Aid for Harvesting policy, all three price levels are significantly sensitive to the processing yield realizations in Financial Aid Improvement for Processing Policy.

- Low (high) processing yield leads to increases (decreases) in all price levels.

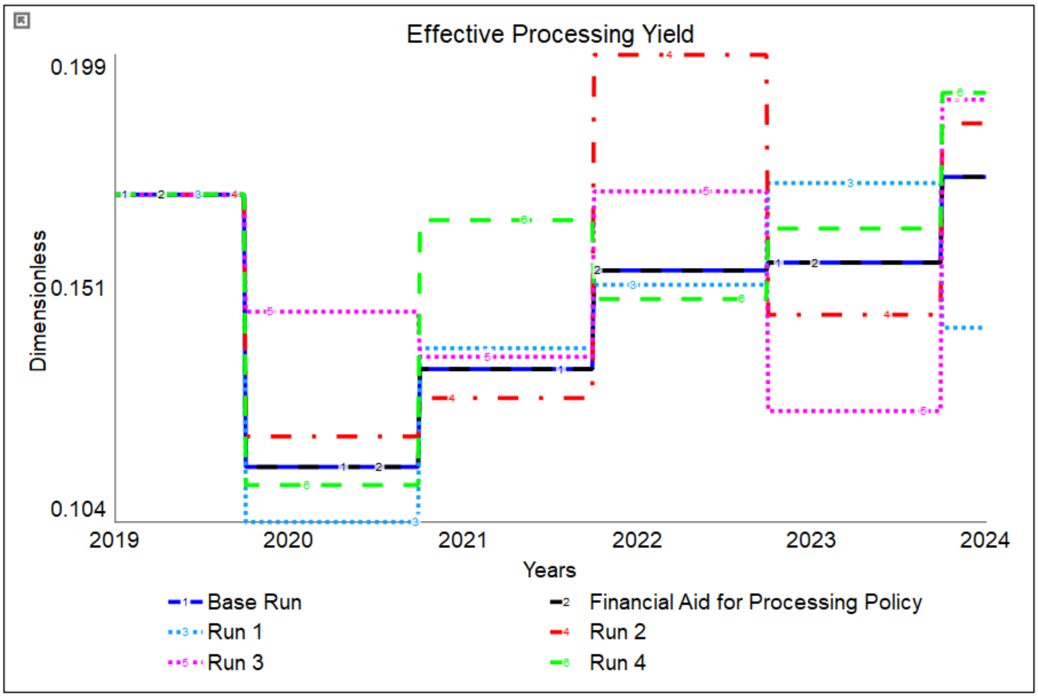

Figure 9.26: Different Processing Yield Values in Financial Aid Improvement for Processing Policy

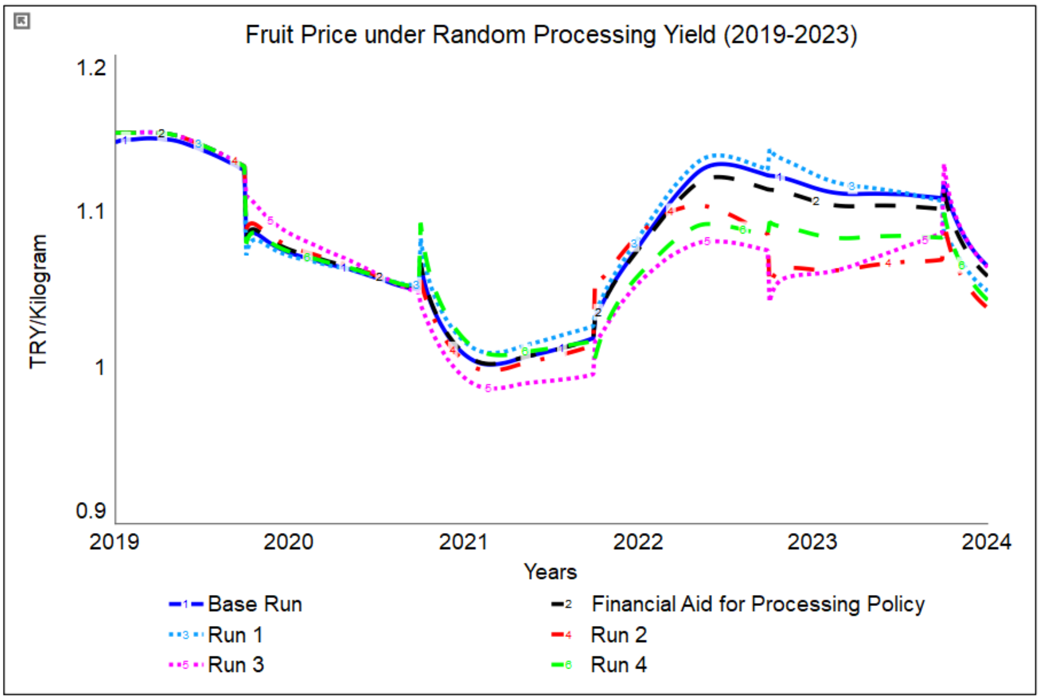

Figure 9.27: Fruit Price in Financial Aid Improvement for Processing Policy under Different Scenarios of Processing Yield

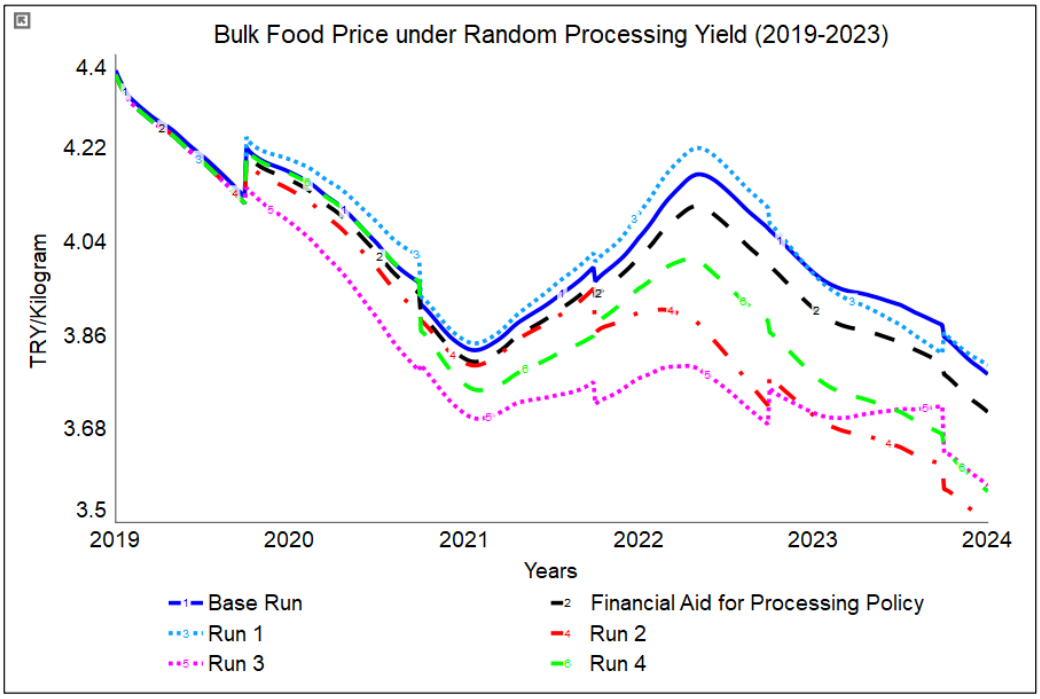

Figure 9.28: Bulk Food Price in Financial Aid Improvement for Processing Policy under Different Scenarios of Processing Yield

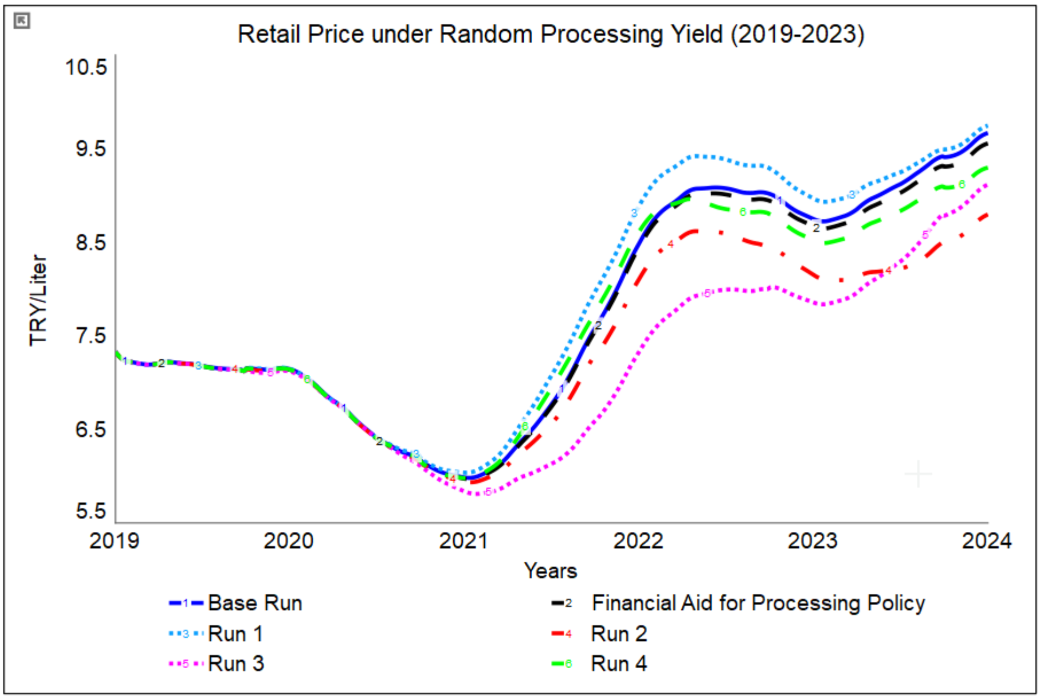

Figure 9.29: Retail Price in Financial Aid Improvement for Processing Policy under Different Scenarios of Processing Yield

- Low processing yield realizations may suppress the benefits of the policy implementation and the resulting price level may be higher than the base run results (as in Run 1, light blue dotted line in Figures 9.27, 9.28 and 9.29).
- When a worse (better) year is followed by a better (worse) year in terms of processing yield (see Run 1 and Run 3 for years 2021-2022 and 2022-2023), prices exhibit harsh turns in their behavioral directions (especially, see Figure 9.27 for Fruit Price and Figure 9.28 for Bulk Price, respectively). The reasons behind these behaviors are the unexpected changes in supply and demand ratio, and the effects among different price levels.
- When the mean absolute percent deviation from the expected behavior of the price is considered, the most sensitive stage to Processing Yield is observed to be Processing.

For this policy, we make an additional analysis and inquire the question: what if processing yield realizations happen to be lower than expected (as in Run 1, light blue dotted line in Figure 9.26) and no policy is implemented? What is the benefit of implementing Financial Aid Improvement for Processing policy in a pessimistic olive oil yield scenario? The graphical results of this analysis are presented in Figures 9.30, 9.31 and 9.32. In the graphs, the dark blue line shows the Base Run results (neither this policy nor olive oil yield scenario is implemented), the black dashed line shows the Financial Aid Improvement for Processing policy run (only policy is implemented but olive oil yield is the same as the Base Run), the light blue dotted line shows the Financial Aid Improvement for Processing policy results under a random run which happens to be pessimistic (both the policy and the olive oil yield scenario are implemented) and finally the green dashed line shows the pessimistic scenario case when no policy is implemented.

The major observation gathered from this comparative analysis is that, if the policy is not implemented, the situation worsens in terms of increases in all three price levels. Another observation is, the similarity of the patterns of price levels under the same olive oil yield scenario (especially see "Run 1 with Policy" and "Run 1 without Policy" results in Figures 9.33 and 9.34). This observation reveals the significance of olive oil processing yield on the behavior pattern of prices.

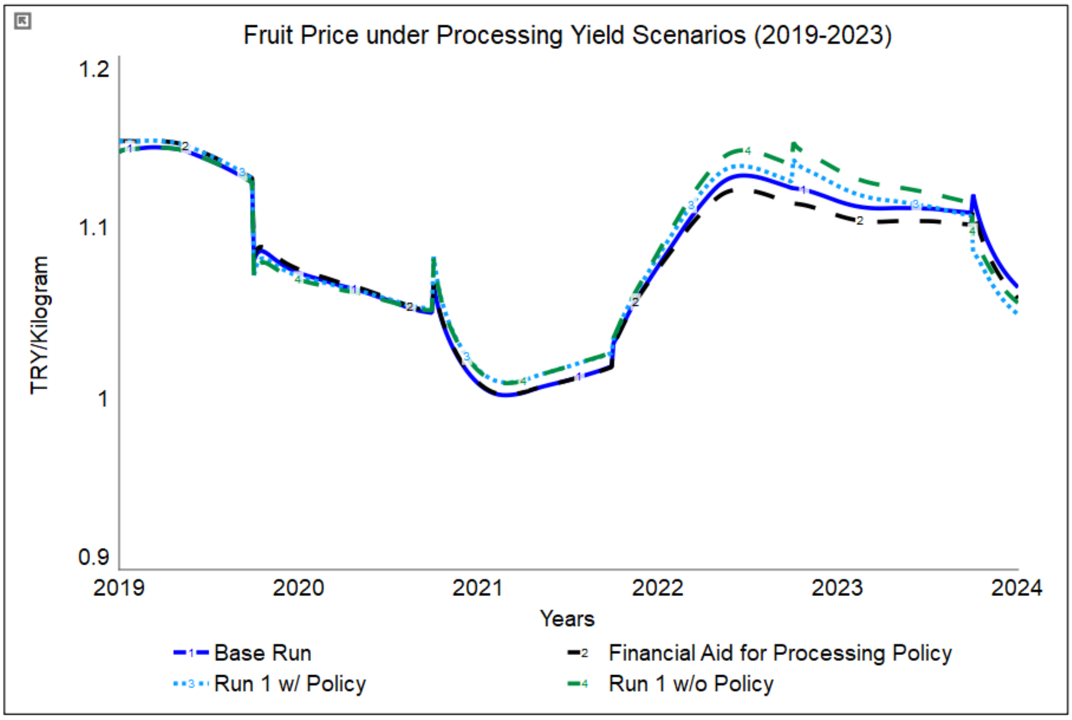

Figure 9.30: Fruit Price: Comparative Analysis for Financial Aid Improvement Policy under a Pessimistic Olive Oil Yield Scenario

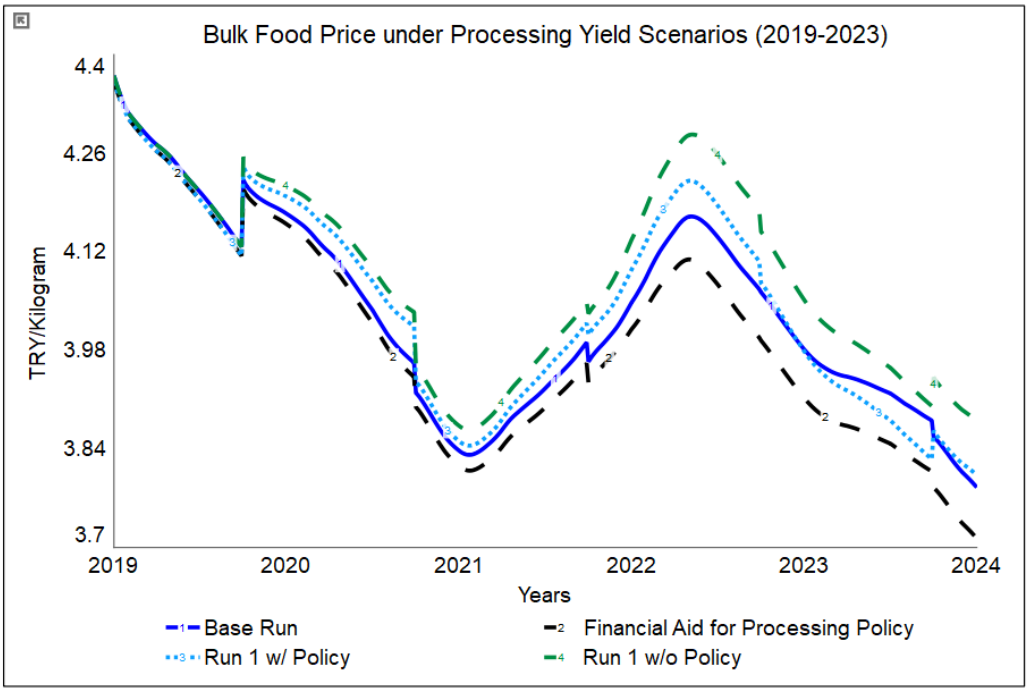

Figure 9.31: Bulk Food Price: Comparative Analysis for Financial Aid Improvement Policy under a Pessimistic Olive Oil Yield Scenario

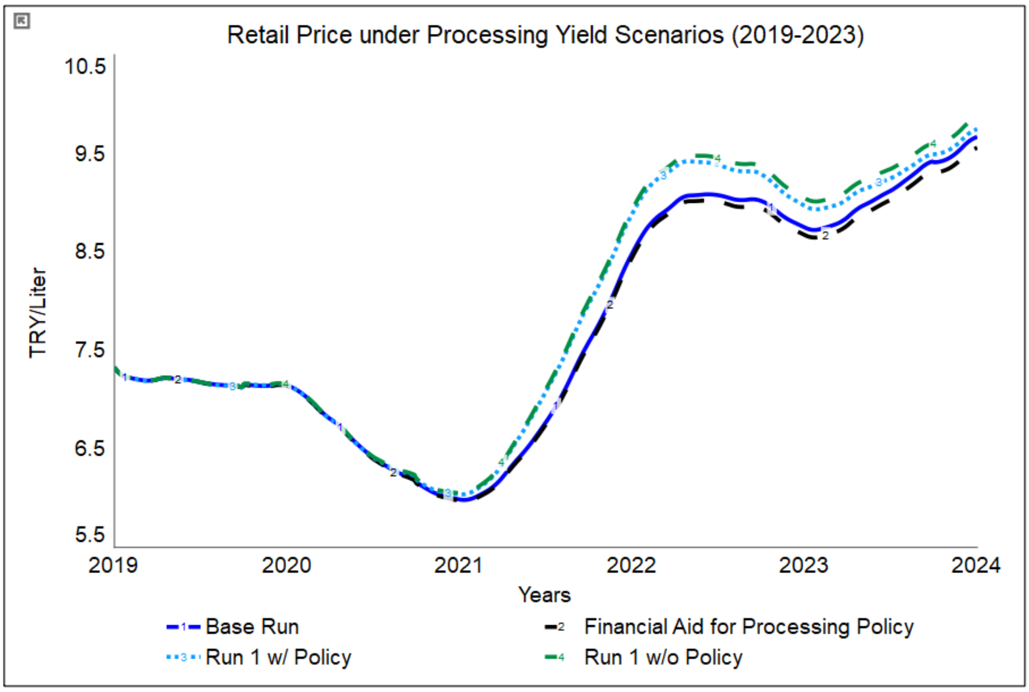

Figure 9.32: Retail Price: Comparative Analysis for Financial Aid Improvement Policy under a Pessimistic Olive Oil Yield Scenario

9.2.3 Policy 3: Empowering Cooperative Action - Improvement in Fixed Costs

As it is previously mentioned, the cooperative organization in Turkish olive oil industry is not as high when compared to the cases in Spain, Greece and Portugal. One role of unions and cooperatives is supporting the olive farmers and olive oil producers by supplying agricultural inputs. Since olive growing and olive oil processing sectors have many small producers in Turkey, participants are not able to benefit from the economies of scale, and "Turkey is considered a relatively high-cost producer in the global market" (Lynch and Rozema, 2013).

As the third policy, we analyze the value chain benefit and change in social welfare as a result of empowering the cooperative action in Turkey, and hence, the improvement in fixed costs of olive growing stage. For this policy analysis, it is considerably hard to monetize the cost or government expenditure to empower the cooperatives in Turkey. Hence, to assess the policy, we make a comparative analysis for the benefit of improving Fixed Costs of Growing by 5%, 10% and 20%. The comparative analysis results for prices are given in Figures 9.33, 9.34 and 9.35.

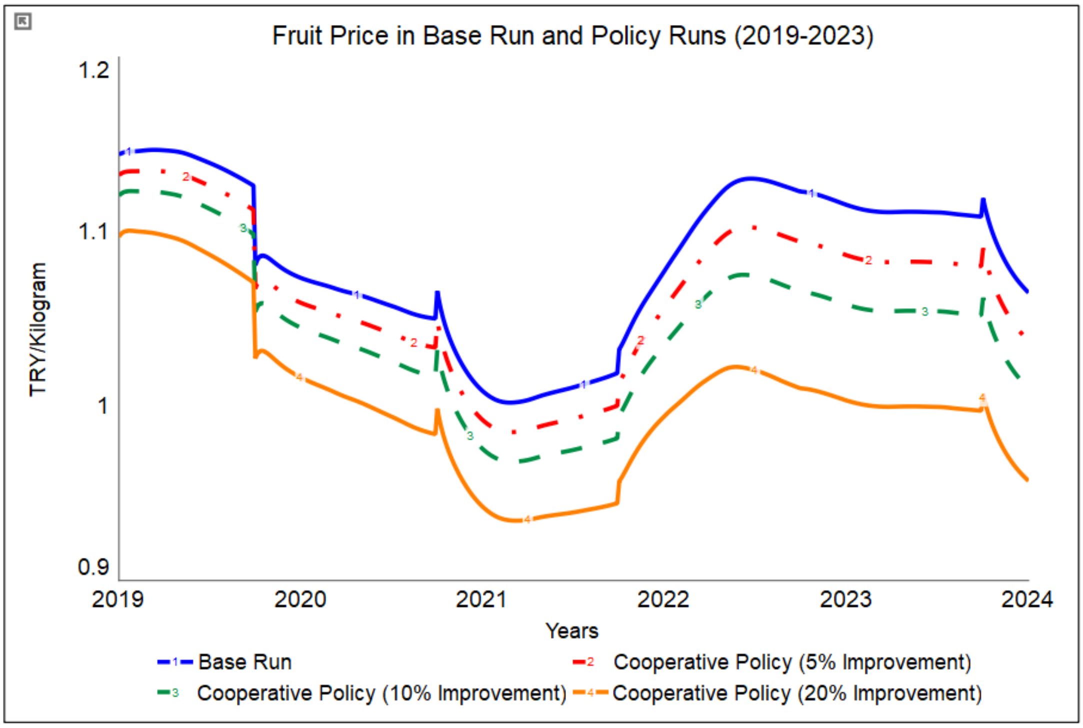

Figure 9.33: Fruit Price: Base Run and Cooperative Empowerment Policy Runs

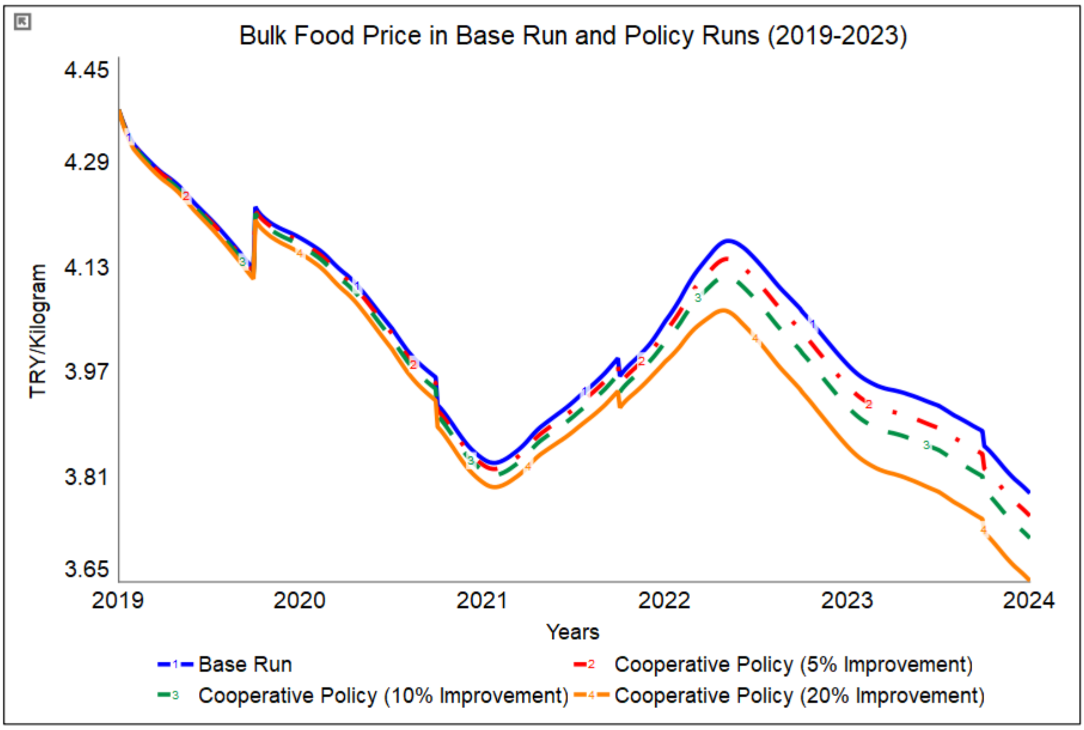

Figure 9.34: Bulk Food Price: Base Run and Cooperative Empowerment Policy Runs

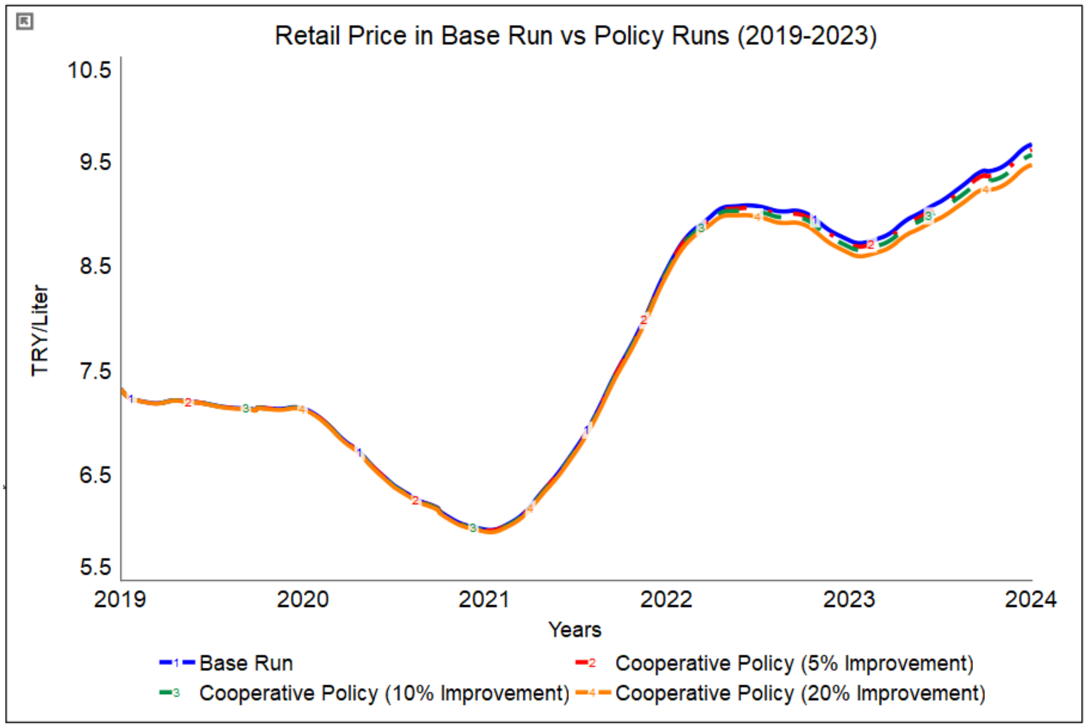

Figure 9.35: Retail Price: Base Run and Cooperative Empowerment Policy Runs

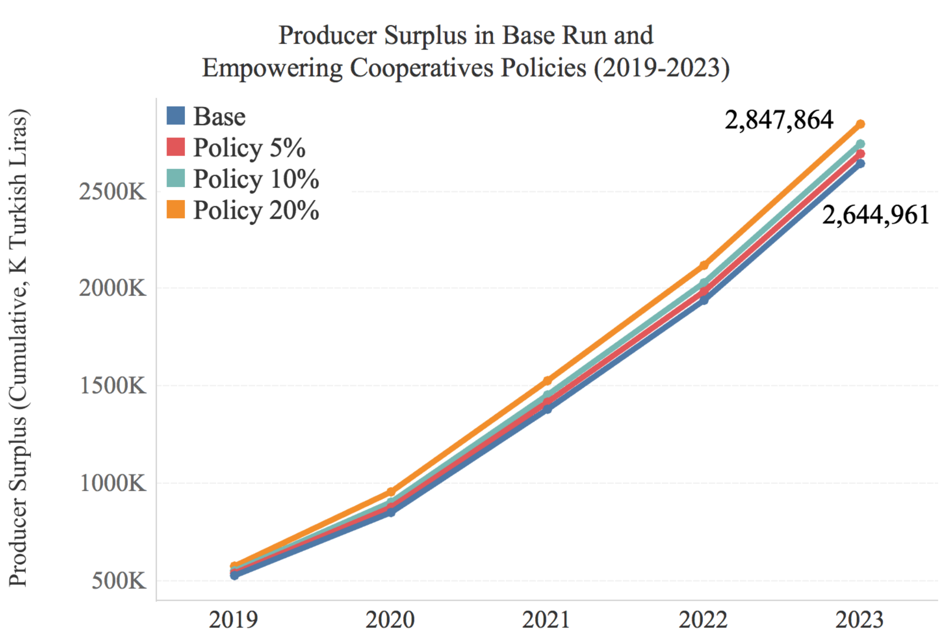

Figure 9.36: Producer Surplus: Base Run and Cooperative Empowerment Policy Runs

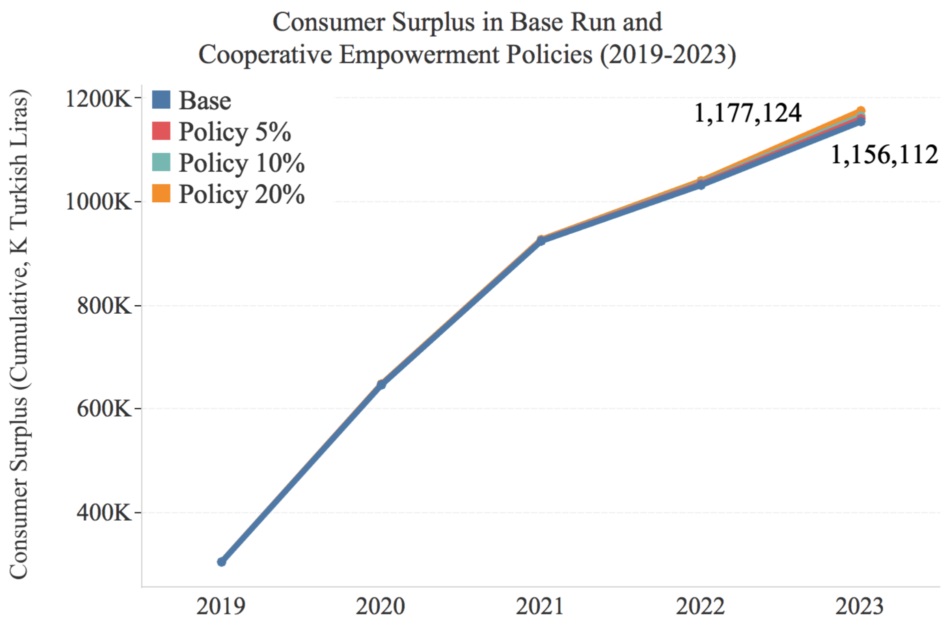

Figure 9.37: Consumer Surplus: Base Run and Cooperative Empowerment Policy Runs

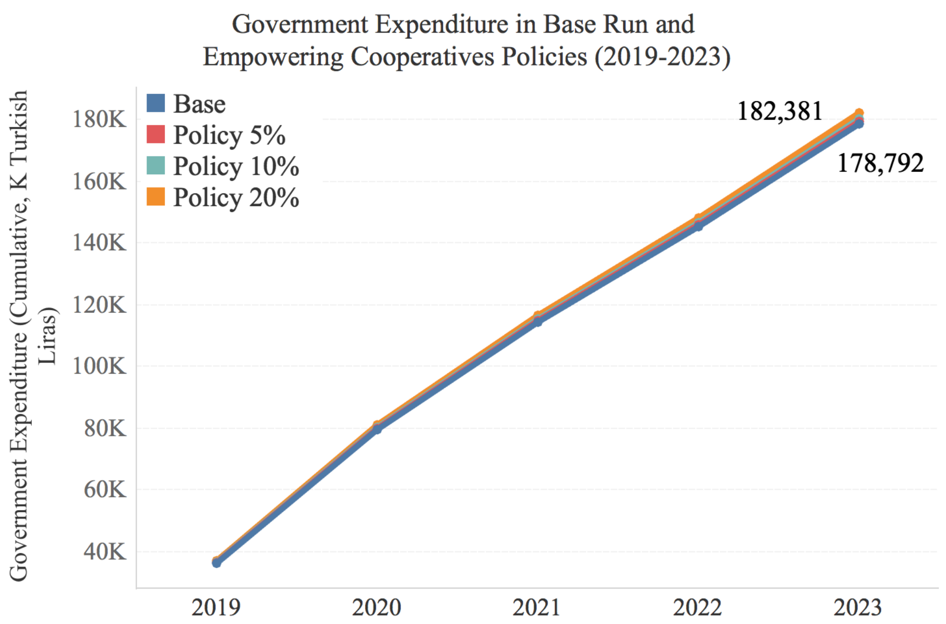

Figure 9.38: Government Expenditure: Base Run and Cooperative Empowerment Policy Runs

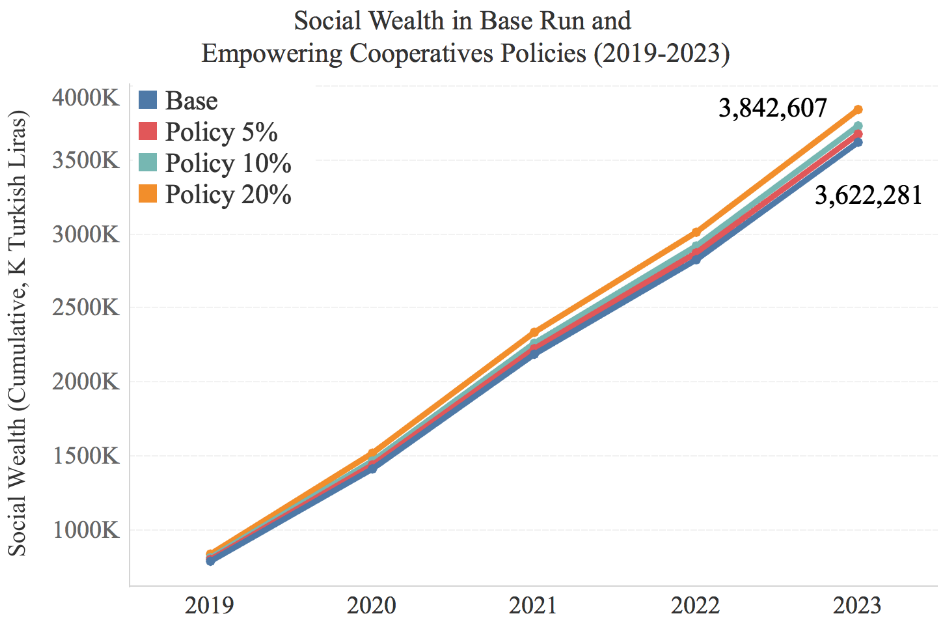

Figure 9.39: Social Wealth: Base Run and Cooperative Empowerment Policy Runs

Table 9.6: Economic Indicators for the Empowering Cooperative Action Policies (Base and 5%) during 2019-2023 (in K TRY, Real)

Indicator	**Base Run**		**5% Improvement**		
Total Planting Cost	20,003		21,485		$\Uparrow$
Government Expenditure for Planting	10,561		11,349		$\Uparrow$
	Fruit Sellers	Bulk Sellers	Fruit Sellers	Bulk Sellers	
Total Growing and Harvesting Cost	275,908	2,483,170	269,340	2,424,057	$\Downarrow$
Total Revenue from Growing and Harvesting	671,077	0	657,350	0	$\Downarrow$
Government Expenditure for Growing and Harvesting	11,811	106,300	11,814	106,325	$\Uparrow$
Total Earning from Growing and Harvesting	406,981	0	399,824	0	$\Downarrow$
Total Value Added at Growing and Harvesting	395,170	0	388,010	0	$\Downarrow$
Total Cost of Olive Oil Processing	1,040,816		1,027,178		$\Downarrow$
Total Revenue from Bulk Olive Oil	3,304,558		3,291,246		$\Downarrow$
Government Expenditure for Olive Oil Processing	50,120		50,102		$\Downarrow$
Total Earning from Olive Oil Processing	-63,008		-3,562		$\Uparrow$
Total Value Added at Olive Oil Processing	-219,428		-159,989		$\Uparrow$
Total Cost of Olive Oil Packaging	4,060,046		4,046,375		$\Downarrow$
Total Revenue from Olive Oil Packaging	6,370,475		6,355,586		$\Downarrow$

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Table 9.6 – *Continued from previous page*

Indicator	**Base Run**	**5% Improvement**	
Total Earning from Olive Oil Packaging	2,310,429	2,309,211	$\Downarrow$
Total Value Added at Olive Oil Packaging	2,310,429	2,309,211	$\Downarrow$
Total Value Added along the Chain	2,466,168	2,515,747	$\Uparrow$
ΔCS_P	-	5,468	$\Uparrow$
ΔPS_P	-	50,377	$\Uparrow$
ΔGE_P	-	798	$\Uparrow$
ΔW_P	-	55,047	$\Uparrow$

Table 9.7: Economic Indicators for the Empowering Cooperative Action Policies (10% and 20%) during 2019-2023 (in K TRY, Real)

Indicator	**10% Improvement**		**20% Improvement**		
Total Planting Cost	23,074		26,634		⇑
Government Expenditure for Planting	12,194		14,085		⇑
	Fruit Sellers	Bulk Sellers	Fruit Sellers	Bulk Sellers	
Total Growing and Harvesting Cost	262,777	2,364,993	249,671	2,247,039	⇓
Total Revenue from Growing and Harvesting	643,776	0	617,111	0	⇓
Government Expenditure for Growing and Harvesting	11,817	106,354	11,825	106,424	⇑
Total Earning from Growing and Harvesting	392,816	0	379,265	0	⇓
Total Value Added at Growing and Harvesting	380,999	0	367,440	0	⇓
Total Cost of Olive Oil Processing	1,013,690		987,196		⇓
Total Revenue from Bulk Olive Oil	3,278,193		3,252,914		⇓
Government Expenditure for Olive Oil Processing	50,083		50,048		⇓
Total Earning from Olive Oil Processing	55,947		175,149		⇑
Total Value Added at Olive Oil Processing	-100,490		18,678		⇑
Total Cost of Olive Oil Packaging	4,032,972		4,007,037		⇓
Total Revenue from Olive Oil Packaging	6,341,044		6,313,037		⇓

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Table 9.7 – *Continued from previous page*

Indicator	**10% Improvement**	**20% Improvement**	
Total Earning from Olive Oil Packaging	2,308,071	2,306,000	$\Downarrow$
Total Value Added at Olive Oil Packaging	2,308,071	2,306,000	$\Downarrow$
Total Value Added along the Chain	2,565,506	2,665,484	$\Uparrow$
ΔCS_P	10,782	21,011	$\Uparrow$
ΔPS_P	100,993	202,904	$\Uparrow$
ΔGE_P	1,656	3,588	$\Uparrow$
ΔW_P	110,120	220,327	$\Uparrow$

The comparative analysis results for producer surplus, consumer surplus, government expenditure, social wealth are given in Figures 9.36, 9.37, 9.38, 9.39, respectively. Other economic indicators are comparatively presented in Tables 9.6 and 9.7.

The major observations gathered from the results are given below:

- Decrease in Fixed Costs of Growing considerably affect and decrease all three price levels well below the Base Run results.
- When the whole chain is considered, Total Value Added along the Chain increases with the improvement in Fixed Costs of Growing.
- Empowering cooperative action by decreasing Fixed Costs of Growing considerably affect and improve both producer and consumer surpluses.
- With decreasing Fixed Costs of Growing, Total Earning and Total Value Added at Growing and Harvesting have slightly and unexpectedly decreased. The reason of the decrease is the nonlinear relationship between the Fixed Cost of Growing and Effect of Growing and Harvesting Costs on Fruit Price, and the magnitude of Sensitivity of Fruit Price to Growing and Harvesting Costs. Figure 9.40 shows the resulting Effect of Growing and Harvesting Costs on Fruit Price for changing values of improvement in Fixed Cost of Growing. When Fixed Cost of Growing is immediately decreased, the reaction of Effect of Growing and Harvesting Costs is sharper first, then gets closer to the Base Run results. Hence, Total Earning and Total Value Added at Growing and Harvesting lie slightly below the base run results.
- Through decreasing Fixed Costs of Growing, the net social wealth of the whole value chain has increased. When the change in social wealth is comparatively analyzed among 5%, 10% and 20% improvements in fixed costs, the benefits are found to be proportional to the improvement ratio.
- The change in social wealth can be used as an indicator to assess the benefits of the policy: if the cost and/or governmental expenditure to empower the cooperative action is predicted to be less than the corresponding change in social wealth, then the policy can be assessed as "worth" to be considered and implemented.

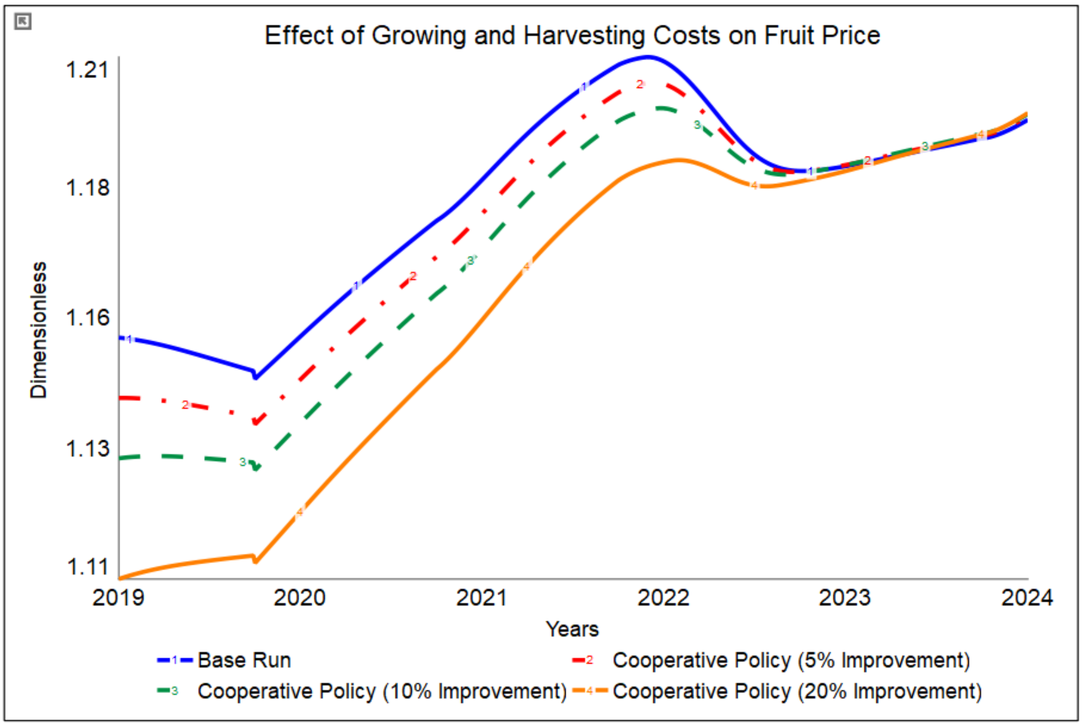

Figure 9.40: Effect of Growing and Harvesting Costs on Fruit Price for Changing Values of Improvement in Fixed Cost of Growing

9.3 Implications for Policy Makers

As the result of a series of policy and scenario analysis, the implications for policy makers can be summarized as below:

- Considering the random elements is essential for policy analysis in order to evaluate the robustness of the candidate value chain interventions.
- Not only the income and earnings of the individual stakeholder groups, but also the total value added along the chain should be considered in comparing the policies for a proper policy analysis.
- Among the three sets of policies analyzed, making productivity investments and empowering cooperative action along the chain are found to be creating relatively more value compared to the direct financial supports.
- The traditional approaches in value chain improvement projects should be inquired in terms of investing in the "weakest ring of the chain". Our analyses

show that investing in the “weakest ring of the chain” would not always provide the best results. Policy analyses in financial supports reveal us the fact that financially supporting the farmers at the harvesting stage, has created the highest benefit for the producers at the processing stage.

- The last but not the least, our model does not guarantee to provide the exact solution for the problem. We only provide a framework for a simultaneous policy and scenario analysis tool for value chain improvement. Also it is to be emphasized that, the more accurate data the decision maker has, the better the results and analysis achieved will be.

CHAPTER 10

CONCLUSION AND FUTURE RESEARCH

Our study is set out to investigate the complex price, supply and demand dynamics along the agricultural value chains, and to provide a quantitative analysis in order to assess the value chain improvement policies for olive oil value chain in Turkey.

In this chapter, we first summarize the relationships between the problem background, the modeling purpose and the theoretical implications of our study. Then, we summarize the empirical findings and implications gathered from the policy and scenario analysis conducted for the Turkish olive oil value chain. Then we proceed with the future research opportunities and conclude with the limitations of the study.

Increases and fluctuations in food and agricultural commodity prices are strongly related with the economical sustainability of the stakeholders along the agricultural value chains. In Turkey, stakeholders along the agricultural value chains may encounter with unforeseen fluctuations and increases in agricultural commodity prices. One prominent case of these phenomena has been observed in olive oil value chain in Turkey. As it is discussed in Chapters 2 and 3, despite the increasing population of olive trees and volume of olive harvest in recent years, retail price of olive oil has almost doubled in only one year, starting from the end of year 2014 to the end of year 2015. Having inspired by the olive oil case in Turkey, we aim to understand how value is created along the agricultural value chains.

We remind that our modeling purpose is twofold: (1) to understand the price, supply and demand dynamics along the agricultural commodity value chains and to explain them analytically and mathematically, and (2) to make policy and scenario analyses for the specific case of olive oil value chain in Turkey with the focus of economical sustainability. As Rich et al. (2009) emphasize the necessity for a broader use of quantitative approaches in value chain intervention assessments, we aim to build a framework which supports the policy makers in quantitative assessment of various policies under possible scenarios. Within the scope of the modeling purposes stated above, we utilize system dynamics modeling which is one of the complex system science methods as Higgins et al. (2010) recommend.

Our study requires an interdisciplinary outlook; hence, we review the relevant literature on value chain analysis, and various mathematical modeling studies for problems in agriculture, specifically, system dynamics studies which deal with agricultural commodity markets and value chains. Not only the academic literature but also the relevant non-academic literature which consists of reports published by global and national institutions are utilized in order to capture the dynamics of the Turkish olive oil industry. Among the available agricultural commodity market and value chain studies with system dynamics modeling, our research contributes to the existing literature with a unique model which incorporates the three characteristics below simultaneously:

- including both supply chain (i.e, flow and physical transformation of the product from seed to fork) and value chain (i.e. formation of added cost and price elements during flow and transformation) structures,
- considering the four major market elements, i.e., price, demand, supply, and capacity, endogenously,
- considering complex nonlinear relationships among the price levels in different stages of the agricultural value chain, instead of assuming simple linear relationships, like, for example, the retail price as a linear function of fruit price and a given retail mark-up.

Before investigating the specific case of Turkish olive oil value chain, we first present a generic system dynamics model to represent the price, demand, supply, and capacity dynamics along the value chain of an agricultural commodity with the following characteristics: raw fruits are harvested at specific times of the year and they are perishable when harvested, then they go through some processes and become bulk food which is storable. The system dynamics model is valid for the problem setting in which the agricultural commodities take part in country's exports, but the country is a price taker, rather than a price maker in the world market. This generic model is presented with its structure, variables and analytical relationships. In order to demonstrate the use of the generic model as a policy analysis tool, we perform relevant validity tests to the model and make a quantitative policy analysis with a synthetic data set.

The generic agricultural value chain model is modified accordingly and applied to the specific case of Turkish olive oil value chain model. As a contribution to the system dynamics methodology, we present the modification and application details step-by-step. During the parameter calibration, we build automated calibration models for each module and present the details of each calibration problem. By compiling the relevant guidelines in the literature, we present "calibration checklists" which may help other researchers in the field.

In order to discuss our empirical findings from the quantitative policy and scenario analyses, we recap our dynamic hypothesis: we hypothesize that different price levels along the agricultural value chains (i.e. raw fruit / plant price, processed bulk food price, packaged food retail price) are not the sole summation of the relevant costs and profit margins. As it it shown for the olive oil case in Turkey, price levels may affect each other in both directions along the agricultural value chain: i.e. retail price may affect the bulk food price and similarly bulk food price may affect the retail price; hence, there may be direct feedback loops between price levels. For this reason, we build the system dynamics model accordingly in order to test our hypothesis. In the model validation tests, especially in the behavioral reproduction tests which are detailed in Chapter 8, the hypothesis is not rejected and the model is accepted as valid for our modeling purposes.

After the validation of the Turkish olive oil value chain model, we conduct simultaneous policy and scenario analyses. The relevant policies are selected depending on the available literature which deals with the discontent of the stakeholders along the Turkish olive oil value chain. These policies can be listed as (1) Extensification of Irrigation, (2) Redesign of Financial Support Policies, and (3) Empowering Cooperative Action. We are aware of the fact that agricultural value chains are prone to uncertainties which stem from the nature or the world market conditions. Hence, in addition to controllable policies, we conduct scenario analysis for random levels of Packaged Food Export Price and Processing Yield. The variables for the scenario analysis are selected depending on the behavioral sensitivity tests conducted during the model validation step, that is, we conduct model validity tests, and policy and scenario analyses in an integrated way.

Among the three sets of policies analyzed, making productivity investments and empowering cooperative action along the chain are found to be creating relatively more value compared to the direct financial supports. To the best of our knowledge, our study is unique in conducting quantitative analysis for interventions in an agricultural value chain in Turkey. It is crucial to emphasize that, instead of a point prediction or an exact solution, we provide a framework for a simultaneous policy and scenario analysis tool for value chain improvement. Furthermore, it is to be mentioned again that, the more accurate data the decision maker has, the better the results and analysis achieved will be.

There is a number of future research opportunities that may extend from this study. One set of opportunities is the possible extensions of the olive oil value chain model. The system dynamics model built for the olive oil value chain in Turkey can be extended and modified with the following considerations:

1. Different quality grades: Since both olive fruits and olive oils with different quality grades have different cost, price, supply and demand levels, the model can be expanded in the way that it represents at least two or more different quality grades.

2. Import channels: Since olive oil import values are so small in Turkey, import channels are not included in the olive oil value chain model. Yet, in the near future, policy makers may require to assess the effects of olive oil import to the country. Then both Bulk Olive Oil Import and Packaged Olive Oil Import flows can be added to the model as the outflows of Bulk Food Inventory and Packaged Food Inventory, respectively. In that case, modeling structure of the decision rules that determine the volume of the import flows are also to be added to the

model.

3. Effect of information sharing by the parties in the chain: As the result of the interviews conducted with the stakeholders along the Turkish olive oil value chain, we learn that the critical information shared by some parties may affect the price dynamics. Two important examples of these parties are the leading olive oil cooperative in Turkey, TARİŞ, and National Olive and Olive Oil Council of Turkey (Ulusal Zeytin ve Zeytinyağı Konseyi, UZZK). During the harvest period, TARİŞ announces the purchasing price of bulk olive oil. Under normal conditions, this price is expected to be approximately equal to the perceived/-expected bulk food price level, and hence this announcement is not expected to affect the price dynamics. Yet, when the price announced is significantly below or above the expected price, then it may affect the market prices. Similarly, before the harvest season, UZZK announces the forecasted harvest amount for the following year. If this amount is significantly below or above the expected harvest amount, then the perceived supply and demand ratio may change and it affects the price dynamics. The possible effects of information shared by those parties are not included in the current version of the model. Depending on the requirements of policy makers, the behavior of these parties and their effects can be added to the model.

4. Table olives: In the current model, the behavior in table olives sector are assumed to be given and represented in the model with the variable "Expected Olive Usage Amount for Other Means". Alternatively, if decision makers have hypotheses about the price levels in the table olives market, it may be added to the model as a subsystem; because the production volume and the price of table olives, the profit gained from table olives production and many other variables about table olives subsystem may affect the stakeholders decisions in the industry.

Another major future research opportunity is to model the agricultural value chain with the speculative behavior of stakeholders. For an agricultural commodity market, the stakeholders may exhibit speculative behaviors. In system dynamics literature, the speculative behavior has been modeled for different problem environments: for land market see Mohammadi et al. (2010), for foreign currency markets see Dwenger and Pavlov (2008) and see Cehreli et al. (2017), for stock exchange markets see Benmaran and Saaedi (2014). For speculative behavior in inventory and price dynamics, Peck (2010) provides the results of a study conducted for a paper manufacturer and states the three types of speculative behavior in his problem environment: (1) impact of expected change in price on ordering, (2) impact of expected change in price on operating rate, (3) impact of expected change in price on consuming.

The resulting behavior of the speculative impacts can be explained as follows: stakeholders do not only decide depending on their current "perceived/expected price level" but also on their expectation for the change in price in the near future. For instance, if expected change in price is positive for a consumer, she tends to buy more in order to save her future, even though her current "perceived price level" is higher than her "reference price".

Within the context of our agricultural value chain model, "impact of expected change in price on packaging rate" and "impact of expected change in price on demand" may provide meaningful results. Yet, showing the existence of speculative behavior in a market requires detailed statistical data analysis. The required data for an such analysis might be easier to gather in some markets, like foreign currency markets and stock exchange markets, but, generally it is not available in much detail for agricultural markets.

Besides all of its benefits, our study has got some limitations:

- In almost every stage of the study, we experience lack of data on Turkish olive oil value chain components. One common example of these cases is that, for some data sets for which we need monthly statistics, we had to make implications from the available aggregate yearly data. Another example is that, when the official data on olive oil packaging is examined, we observe that the related data sets do not satisfy the "conservation law of materials". Hence we had to find the deviation between the official data set and the feasible data set. Another example is that, for some data sets, only the data for one point in time was available and hence we used relevant indicators to predict the historical time series of the data.

Even though all historical data sets may not be so accurate and the calibration of model parameters are still open for improvement, our model is still valid for its purpose since system dynamics modeling is a powerful methodology even for data-poor cases.

- As it is explained in detail in Chapter 8, policy analysis for the case of very low levels of Population and GDP would not produce meaningful results. Yet, if the policy analysis is required for very low levels of GDP or Population, these limitations can be resolved by defining table functions or piecewise functions between related cause-and-effect relationships.
- In the model validation tests, behavior sensitivity tests are conducted for a change in one variable at a time in order to determine the parameters to which the model results are sensitive and to question whether these sensitivities would exist in the real world. A more comprehensive sensitivity analysis may be required with changes in multiple variables at a time in order to enrich the implications of policy and scenario analysis. This is a limitation of the current study which stands also as a future research opportunity.

Understanding agricultural value chain dynamics and making policy analysis for development are crucial for the economical sustainability of food and agricultural systems. Our study proposes a generic agricultural value chain model for quantitative policy assessments and illustrates in fine detail the application of the model in Turkish olive oil value chain with relevant policy and scenario analyses. The modeling framework and the policy analysis results in the study are intended to support and direct both the modelers and the policy makers in the field.

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APPENDIX A

GENERIC MODELING STRUCTURES IN AGRICULTURAL VALUE CHAIN MODEL

The appendix chapter is mainly based on definitions and examples given in Sterman (2000).

A.1 Stock-and-Flow Diagram and Its Mathematical Representation

Stocks: Stocks are accumulations and characterize the state of the system. They are represented by rectangles.

Flows: Flows are rates that change the level of stocks. Inflows and outflows are represented by pipes and arrows pointing into or out of the stock.

Clouds: Clouds represent the sources and sinks for the flows. A source represents the stock from which a flow originating outside the boundary of the model arises; sinks represent the stocks into which flows leaving the model boundary drain.

The stock-and-flow diagram representation is given in Figure A.1. An example stock-and-flow diagram for a typical inventory system is given in Figure A.2.

Mathematical representation of relationship between stock and flows is below:

Stock (t) = $\int_{t}^{t_0}$ (Inflow(s) - Outflow(s))ds + Stock (t_0)

d(Stock)/dt = Inflow(t) - Outflow(t)

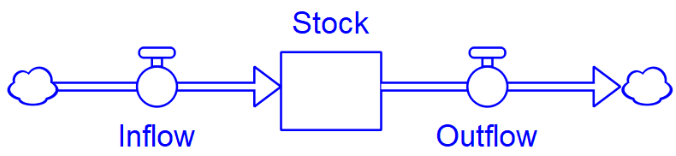

Figure A.1: Stock-and-Flow Diagram

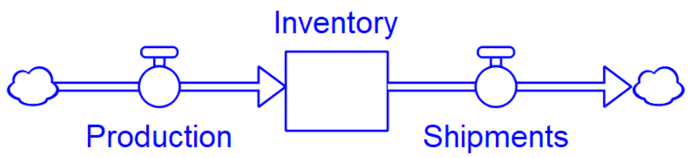

Figure A.2: Stock-and-Flow Example

A.2 Delay Structure

A delay is a process whose output lags behind its input in some fashion. In system dynamics modeling, two typical delay types exist: Material Delay and Information Delay. In STELLA, DELAY built-in function returns the material delay formulations whereas SMTH built-in function returns the information delay formulations.

A.2.1 Material Delay

First Order Material Delay: The outflow from a first-order material delay is always proportional to the stock of material in transit. Its diagrammatic representation is given in Figure A.5 and mathematical representation is given below:

Outflow Rate = Material in Transit / Average Delay Time

Higher Order Material Delay: When a delay consists of multiple stages of processing in which items flow sequentially from one stage to the next, then higher order material delay formulations are required. Diagrammatic representation of a higher order material delay is given in Figure A.4 and its mathematical representation is given below:

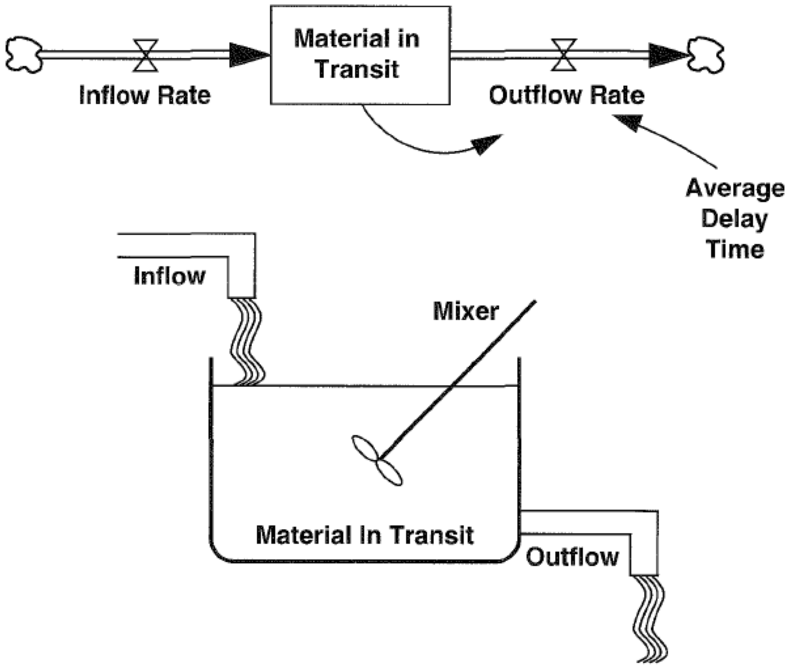

Figure A.3: First Order Material Delay Structure (Sterman, 2000)

Stage 1 Exit Rate = Stage 1 Stock in Transit / Stage 1 Average Delay Time

Outflow Rate = Stage 2 Stock in Transit / Stage 2 Average Delay Time

A.2.2 Information Delay

First order information delay: The simplest information delay and one of the most widely used models of belief adjustment and forecasting is called "exponential smoothing" or "adaptive expectations". Adaptive expectations mean the belief gradually adjusts to the actual value of the variable. Figure A.5 shows the feedback structure of adaptive expectations. The mathematical formulation for the first order information delay is given below:

$\hat{X}$ = INTEGRAL(Change in Perceived Value, $\hat{X}(0)$)

Change in Perceived Value = Error/Adjustment Time = (X-($\hat{X}$))/D

Error = Reported Value of Variable (X) - Perceived Value of Variable ($\hat{X}$)

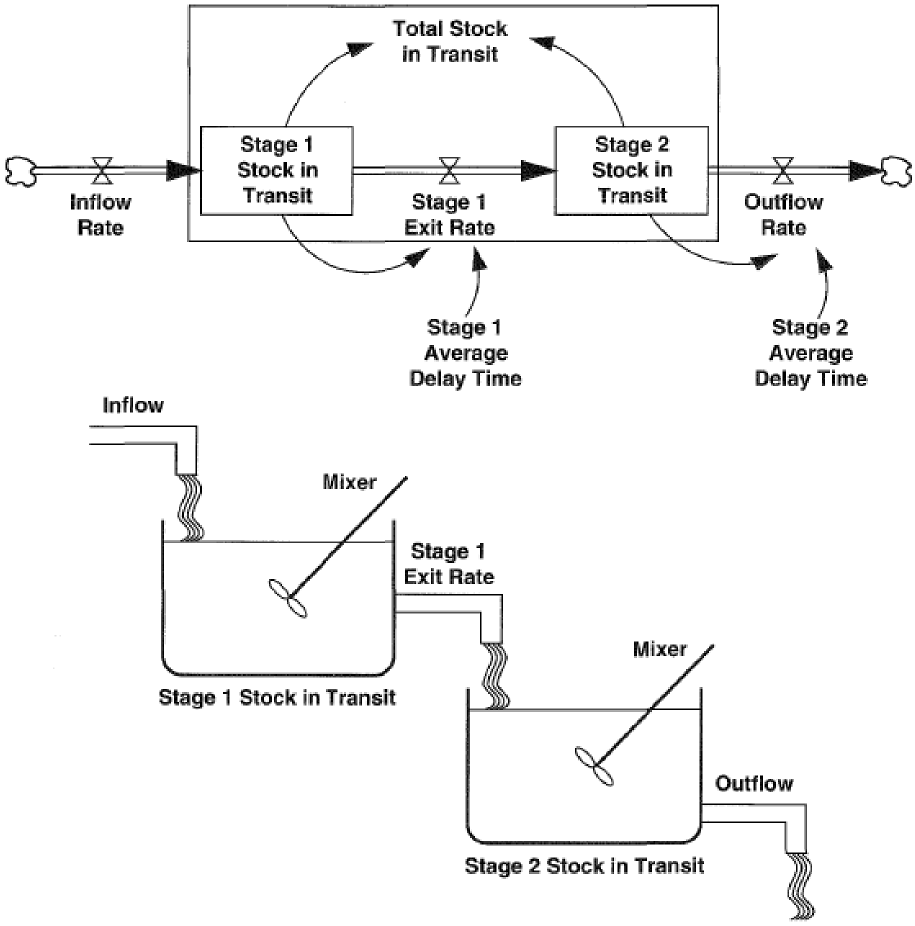

Figure A.4: Higher (Second) Order Material Delay Structure (Sterman, 2000)

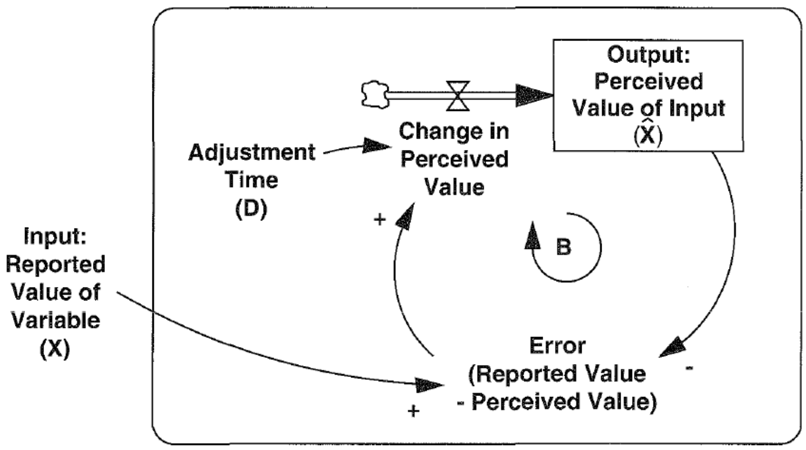

Figure A.5: First Order Information Delay Structure (Sterman, 2000)

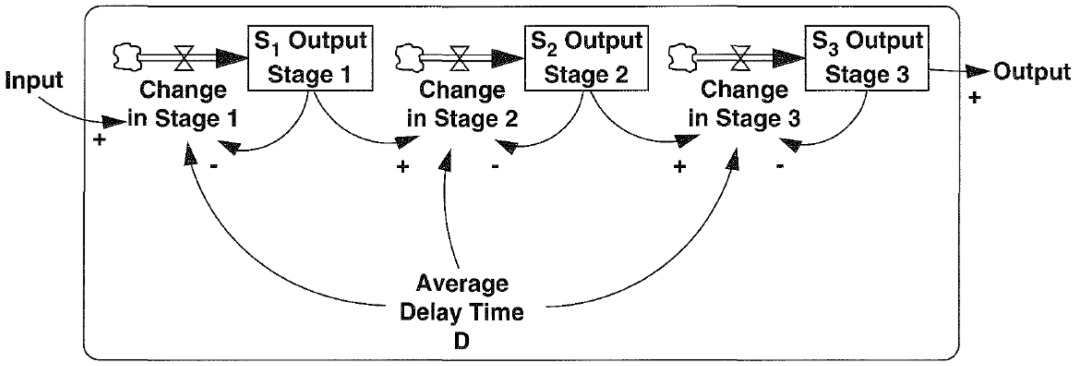

Figure A.6: Higher (Third) Order Information Delay Structure (Sterman, 2000)

Higher order information delay: Information delays in which there are multiple stages are analogous to the multiple stages in material delays and require analogous higher-order delays. Diagrammatic representation of a higher order information delay is given in Figure A.6 and its mathematical representation is given below:

Output = SMTH3(Input, D) is equal to:

Output = S_3

S_3 = INTEGRAL (Change in Stage 3, $S_3(0)$)

Change in Stage 3 = (S_2 - S_3)/(D/3)

S_2 = INTEGRAL (Change in Stage 2, $S_2(0)$)

Change in Stage 2 = (S_1 - S_2)/(D/3)

S_1 = INTEGRAL (Change in Stage 1, $S_1(0)$)

Change in Stage 1 = (Input - S_1)/(D/3)

A.3 Adjustment to a Goal

Decision makers often seek to adjust the state of the system until it equals a goal or desired level. The simplest formulation for this negative feedback is:

Rate of Change in State = (Desired State - Actual State) / Adjustment Time

where Adjustment Time is the average time required to close the gap.

A typical example for the production environment is given below:

Production Rate = Perceived Inventory Discrepancy / Inventory Adjustment Time

Perceived Inventory Discrepancy = Desired Inventory - Perceived Inventory

A.3.1 The Stock Management Structure

When there is an outflow from a stock, the adjustment rate formulation will produce a steady state error. The larger the outflow or the longer the adjustment time, the greater the equilibrium shortfall will be. The stock management structure adds the expected outflow to the stock adjustment to prevent steady state error. The mathematical formulation for the stock management structure is as follows:

Inflow = Expected Outflow + Adjustment for Stock

Adjustment for Stock = (Desired Inventory - Perceived Inventory) / Inventory Adjustment Time

The corresponding example for the production environment is given below:

Production = Expected Shipments + Adjustment for Inventory

Adjustment for Inventory = (Desired Inventory - Inventory) / Inventory Adjustment Time

Expected Shipments = SMTH (Shipment Rate, Shipment Averaging Time)

A.4 Effect Formulation Structure

In Agricultural Value Chain Model, like in many system dynamics models, Effect formulations are utilized. There are two general structures for Effect formulations: Multiplicative and Additive.

A.4.1 Multiplicative Effect Formulation

Y = Y^* * Effect of X_1 on Y * Effect of X_2 on Y * ... * Effect of X_n on Y

where Y^* is the normal or reference value of Y, Effect of X_i on Y values are normalized by the normal or reference value of X_i's and Effect of X_i on Y values are dimensionless. The reference levels of Y^* and X^* can be constants or variables representing equilibrium levels, the desired state of the system or the values of the variables at some point in the past.

A common form for Effect of X_i on Y is a power function of the normalized inputs:

$$\text{Effect of } X_i \text{ on Y} = (X_i \,/\, {X_i}^*)^{a_i}$$

where a_i's are the elasticities. With this formulation structure, Y can be expressed as a log-linear function.

A.4.2 Additive Effect Formulation

Y = Y^* + Effect of X_1 on Y + Effect of X_2 on Y + ... + Effect of X_n on Y

where Y^* is the normal or reference value of Y and Effect of X_i's are normal and standardized functions as:

$$\text{Effect of } X_i \text{ on Y} = \text{f}\,(X_i \,/\, {X_i}^*)$$

where f(1) = 0.

A.4.3 Choice of Effect Formulation Structure

In Effect formulations in our model, we choose to use multiplicative structures. The reasons behind this choice can be listed as follows (depending on the advantages and the disadvantages of both formulations stated by Sterman (2000)):

1-The additive formulation assumes that the effects of each input are strongly separable. Yet, effects in our agricultural commodity model are not strongly separable, especially when there are several effects for a single variable.

2-In the additive formulations, effects must have units and magnitudes that must be comparable with output values and well calibrated with respect to each other. Moreover, additive formulations require the consideration of negative values. These considerations make the model calibration and validation harder.

3-In the reviewed literature on commodity market models with system dynamics, general attitude for effects formulations is towards using multiplicative functions. In fact, limited by the reviewed literature, we have not observed any additive formulations for price, demand and supply modeling.

Hence, we proceed with the multiplicative formulations for "Effect of X_n on Y" variables.

A.5 Anchor-and-Adjust (Floating Goals) Structure

For the cases where goals are not completely exogenous to the decision and the desired state of the system is, at least partially, affected by the state of the system itself, then anchor-and-adjust (floating goals) structure can be used. The stock and flow diagram for a pure floating goal structure is given in Figure A.7 and the corresponding mathematical formulations are given below:

S = INTEGRAL(Net Change in Stock, S_{t_0}) where S is Actual State of the System.

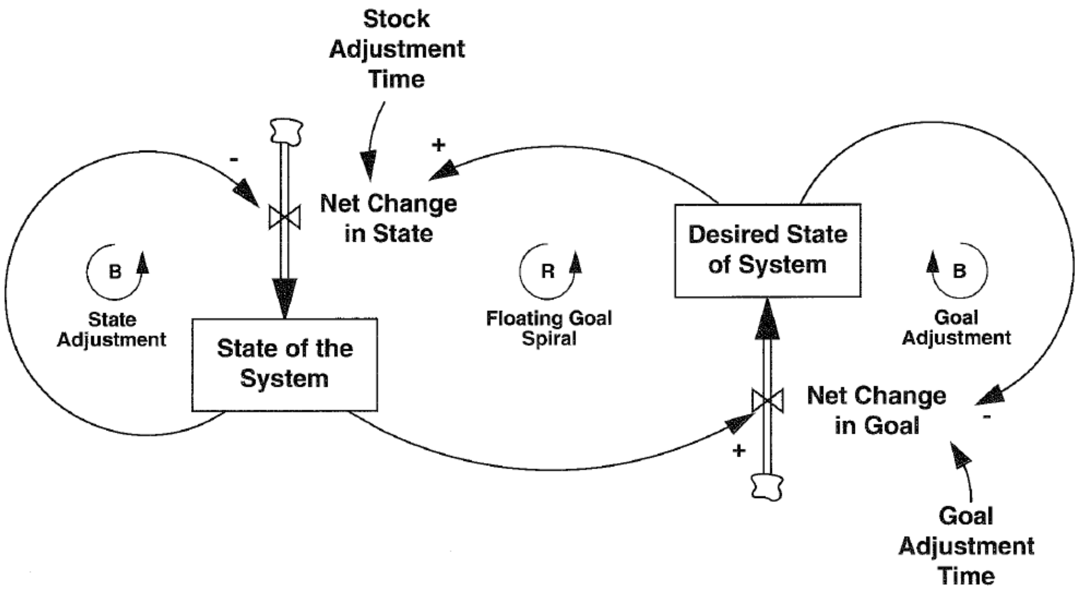

Figure A.7: Anchor-and-Adjust Structure (Sterman, 2000)

Net Change in Stock = $(S^* - S)$/SAT where S^* is Desired State of the System and SAT is Stock Adjustment Time.

S^* = INTEGRAL(Net Change in Goal, ${S^*}_{t_0}$).

Net Change in Goal = $(S - S^*)$/GAT where GAT is Goal Adjustment Time.

A.6 Hill-Climbing Search Structure

Hill-climbing is a very common and often effective heuristic in optimization, decision making and learning. It is analogous to trying to climb a mountain, taking one step in each direction to see which way the ground slopes, then striking out in the direction that leeds most steeply uphill. To model the hill climbing, the desired state of the system is anchored on the current state, then adjusted by various external pressures representing the gradient of the hill and indicating the way uphill. The stock and flow diagram of the general structure for a hill-climbing process is given in Figure A.8 and the corresponding mathematical formulations are given below.

S = INTEGRAL(Change in State of System, S_{t_0}) where S is State of System.

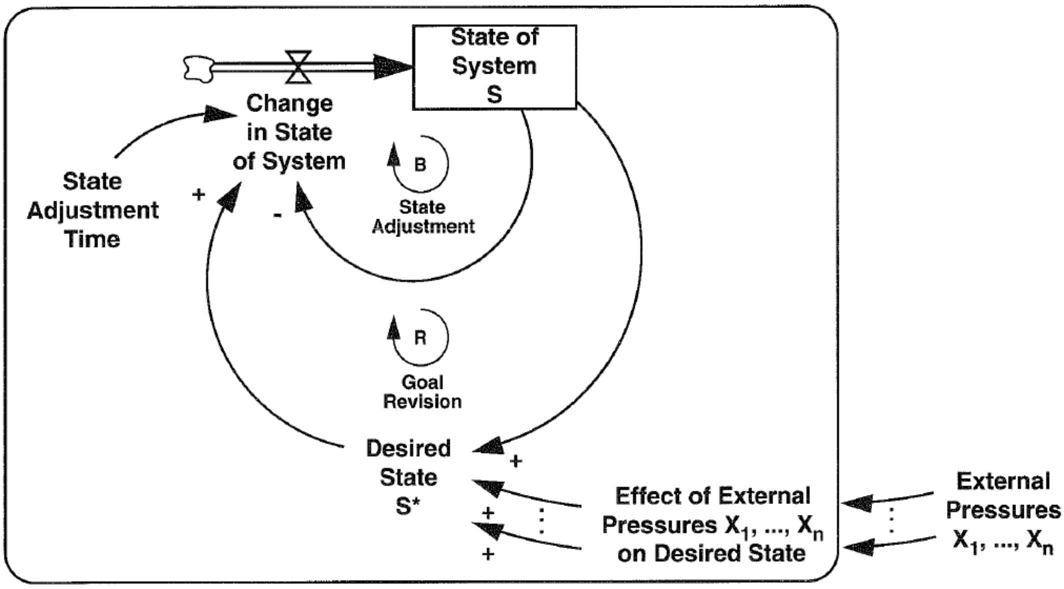

Figure A.8: Hill Climbing Search Structure (Sterman, 2000)

Change in State of System = $(S^* - S)$/SAT where where S^* is Desired State and SAT is State Adjustment Time.

S^* = S * Effect of X_1 on S^* * Effect of X_2 on S^* * ... * Effect of X_n on S^*

Effect of X_i on S^* = f(X_i/$X_i{}^*$)

A.7 Price Discovery by Hill Climbing Structure

Price setting process in a commodity market can be modeled with hill-climbing structure. The demand for the good falls as prices rise; supply rises as price rises. Prices change when there is an imbalance between supply and demand. Stock-and-flow diagram of price discovery in a commodity market is given in Figure A.9 and the corresponding mathematical formulations are given below.

P = INTEGRAL(Change in Price, P_{t_0}) where P is Price.

Change in Price = $(P^* - P)$/PAT where P^* is Indicated Price and PAT is Price Adjustment Time.

P^* = P*Effect of Demand Supply Balance on Price

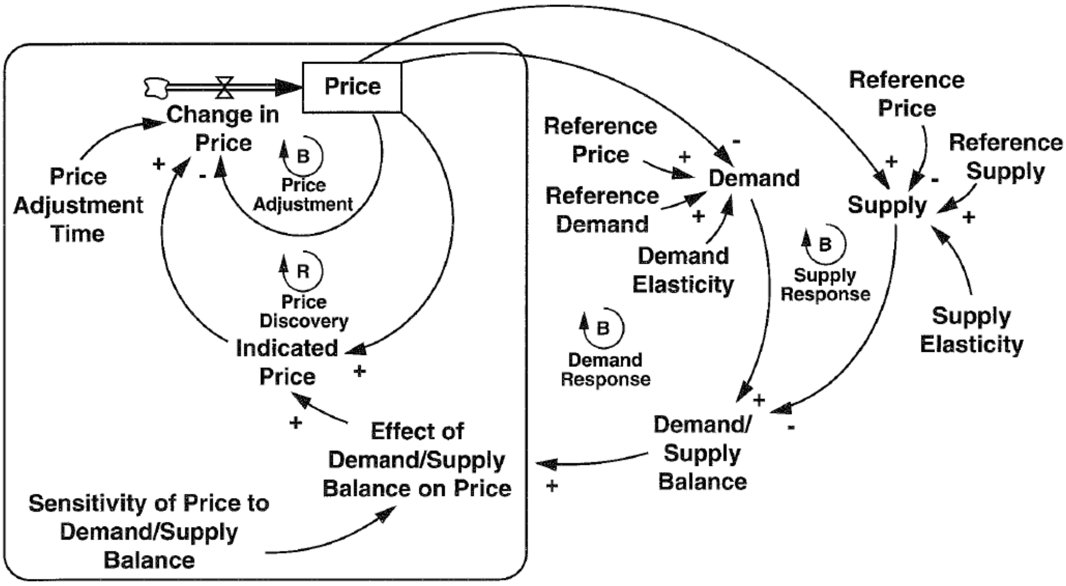

Figure A.9: Price Discovery by Hill Climbing Structure (Sterman, 2000)

Effect of Demand Supply Balance on Price = f(Demand/Supply); f(1) = 1, f’ ≥ 0

Effect of Demand Supply Balance on Price = (Demand/Supply)^{s} where $s > 0$ is the Sensitivity of Price to the Demand/Supply Balance.

Demand = Reference Demand*Effect of Price on Demand

Effect of Price on Demand = (Price/Reference Price)^{e_d} where $e_d < 0$ is Elasticity of Demand.

Supply = Reference Supply*Effect of Price on Supply

Effect of Price on Supply = (Price/Reference Price)^{e_s} where $e_s > 0$ is Elasticity of Supply.

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2. Atamer Balkan, B., & Meral, S. "Olive Oil Industry Dynamics: The Case of Turkey", Proceedings of 35th International Conference of the System Dynamics Society (2017).
3. Atamer Balkan, B., & Meral, S. "Olive oil value-chain dynamics: the Turkish olive oil industry case", Acta Horticulturae, In VIII International Olive Symposium 1199, pp. 195-202 (2016).
4. Atamer B., Bakal I.S. & Bayındır P. "Optimal Pricing and Production Decisions in Utilizing Reusable Containers", International Journal of Production Economics, Volume:143, Issue:2, pp. 222-232 (2013).
5. Atamer B., Çetin A.S., Eke D., Oruç S., Sen F., Çilingir C., & Kayalıgil S. "Total Organizational Improvement in Ankara Post Processing Center", Endüstri Mühendisligi Dergisi, Volume:19, No:3, pp. 17-34 (2008).

FOREIGN LANGUAGES

Advanced English, Basic German