A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: A system dynamics approach

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Abstract

This study investigates a supply chain of perishable fruits and vegetables. A simulation model using system dynamics approach is proposed to study the behaviors and relationships within the supply chain and to determine the impact of the supply, demand and price interactions. The proposed model yields an insight into the overall agricultural system, taking into account the influence of import quota policies. The purpose of this study is to develop a multi-objective model identifying the best import quota policy for Tehran Municipality Organization of Fruits and Vegetables. The multi-objectives are considered to be price mean, price variation and markup. Key conclusions were reached on how to conduct the multi-objective analysis with the aim of import quota policy making. The multi-objective analysis provides not a single solution but a complete non-dominated set of alternatives as potential compromise solutions among multiple objectives. A close examination of surface and contour plots reveals informative trade-offs. The obtained Pareto frontier contour plots assist decision makers to develop quick import quota policies by presenting a range of choice available to decision makers and providing them with the trade-off information among multiple objectives effectively.

1. Introduction

One of the main economic sectors of developing countries such as Iran is agriculture. The potential of agricultural development in Iran is so considerable that different types of agricultural products were exported with the value of more than 3.7 billion dollars in 2010, which was more than four times the value in 2009. Furthermore, the total agricultural export quantity of IRAN was near 3.4 million tons in 2010 which was more than three times the value in 2009 (FAOSTAT, 2012). Fruits and vegetables exports constitute 70% of the total agricultural product exports, which had been steadily growing with the rate of 30% from 2009 to 2010 (Iran Ministry of Agriculture, 2011). However, imports of fruits and vegetables were 2.5 billion dollars in 2010, which were as high as the total exports (The Islamic Republic of Iran Customs Administration (IRICA), 2011). According to the high influence of imports on Iran’s agricultural market, it is indispensable for governmental decision makers to set import quota policies more meticulously in fruit and vegetable supply chains. This not only leads to a smoothed and reasonable price for the final consumers, but also eventuates in supporting the domestic producers more extensively.

Year 2012 has been named as the year of domestic production in Iran in order to support Iranian producers. Even though the government attempts to support domestic agricultural producers with reducing import quotas, this reduction leads to an extensive increase in the prices of different products and final consumers’ dissatisfaction. Hence, Iranian government faces several challenges including a decrease in people’s purchasing power and its following dissatisfaction, and a reduction in domestic product’s sales. Thus, restoring market balance with the aim of reducing price fluctuations, and providing a long-term stability with the domestic production is essential. This paper attempts to investigate the import quota policy in a supply chain of perishable fruits and vegetables. This aim is achieved by proposing a simulation model in a system dynamics framework.

The critical components of fruit and vegetable supply chains include supply, demand, and price for supply chain members including farmers, wholesalers, and retailers. Price variability at all levels of supply chain occurs due to dynamic factors such as substitute goods price, inflation, import, export, production costs, customer demands.

The purpose of this study is to develop a multi-objective model identifying the best import quota policy from the government’s point of view. Therefore, using a simulation model, the study investigates the impact of supply and demand interactions on the price of...
perishable products in a fruit and vegetable supply chain through a system dynamics approach (Forrester, 1990, 1999; Sterman, 2000).

Since the mathematical difficulties imposed by the supply and demand interactions in a multi echelon supply chain prevent the construction of closed form analytical models, we utilize computer simulation for analysis. Owing to the fact that simulation models can describe highly complex systems, system dynamics approach is utilized to highlight the issues and relationships surrounding the complex perishable fruit and vegetable supply chain.

This paper is organized as follows. Section 2 reviews relevant literature. Section 3 discusses the logic of simulation model. Section 4 presents the quantitative validation and analyses the model by defining some scenarios for various conditions. Finally, Section 5 provides multi-objective analysis results and discussion for import quota policy making.

2. Literature review

This section presents the current research in the fruit and vegetable supply chains, as well as, import policy making in agricultural markets, system dynamics modeling and multi-objective analysis.

2.1. Fruit and vegetable supply chains

The supply chain of agricultural products has been widely paid attention in recent years (Ahumada and Villalobos, 2009; Boudahri et al., 2011a, 2011b). Ahumada and Villalobos (2009) identify two main types of agricultural supply chains: fresh agri-foods supply chain and non-perishable agri-foods supply chain. They review fresh products owing to their logistic complexity, their limited shelf life, and the renewed interest of the public on the safety of these products. The present study also analyzes fresh agri-foods supply chain, which includes highly perishable crops such as fresh fruits and vegetables whose useful life can be measured in days.


Several studies have applied mathematical modeling techniques to optimize fruit and vegetable supply chain performance indicators. In particular, Rong et al. (2011) provide a mixed-integer linear programming model used for production and distribution planning in a food supply chain. On the other hand, price variability in fruit and vegetable supply chain has not been thoroughly investigated. Nevertheless, Lambert and Miljkovic (2010) demonstrate the influence of farm commodity prices, energy costs, and other factors on food prices in the United States.

2.2. Import policy making in agricultural markets

Several recent studies have been done to investigate export-import issues (Gorman and Mori, 1988; Wilson and Preszler, 1993; Chen and Brooks, 1999; Hsu and Wann, 2004; Christou et al., 2005). Richard and Lei (2011) examine the economic implications of tariffs regulations and apply their findings to global markets for fresh apples and fresh oranges. Abbott and Paarlberg (1998) scrutinize several aspects of tariff rate quotas as adopted during tariffication of agricultural policies. However, they have not dealt with the import quota policies with multi-objective approach.

2.3. System dynamics modeling

The main research on system dynamics modeling in supply chain management focuses on information sharing, bullwhip effect, inventory planning/management, supply chain integration, system performance, planning and forecasting demand and production planning and scheduling (Tako and Robinson, 2012).

Kumar and Nigmatullin (2011) investigate the non-perishable product food supply chain performance under a monopolistic environment. They apply system dynamics approach to determine the impact of demand variability and lead-time on supply chain performance. Özbayrak et al. (2007) propose a modeling framework to simulate the operation of a supply chain network. They focus on measuring the supply chain performance metrics such as inventory, WIP (Work In Progress) levels, backlogged orders and customer satisfaction. Kishimoto and Yamauchi (1987) also design a system dynamic model to investigate Japan citrus market.

Multi-objective analysis for import quota policy making in fruit and vegetable supply chains has been less noticed in the pertinent literature. Nonetheless, Sterman (2000) states some opinions for modeling supply and demand in a single market, but there is no discussion about import policy making in a supply chain.

2.4. Multi-objective analysis

Most of the literature in this section are focused on the application of multi-objective analysis in planning issues in agriculture such as Sarker and Ray (2009) formulating a crop-planning problem as a multi-objective optimization model. In this case, Ahumada and Villalobos (2009) review the planning models in the agri-food supply chain.

There are several studies investigate the price and demand interactions in agricultural systems through multi-objective analysis. From which, Romero (2000) determines an efficient cropping pattern by considering the risk of the producers with a multi-objective (max revenue, min variability) model.

Several other studies apply a multi-objective approach in agricultural context rather than supply and demand interactions. For example, Fuss et al. (2012) take into account the impact of climate change on prices via increased volatility in crop yields. However, the multi-objective import quota policy-making investigated in this study is barely taken into account in the literature.

While past researches exclusively focus on a single market of agricultural products, this research extends the analysis to consider a two-stage supply chain and its complex interactions. As the authors realized, very little theoretical research has been done on the multi-objective analysis for import quota policy making. While many studies have been pursued with system dynamics approach, very few of them have tackled multiple objectives. In this work, we have conducted multi-objective analysis using system dynamics simulation for import quota policy making in an agricultural supply chain.

3. Methods and materials

3.1. Problem characteristics

When a system is complex, a simulation model is normally preferable, for several reasons as it is stated by Altiok and Melamed (2007). The time spent in deriving a solution to an analytical model may be excessive and the modeler may assert that an analytical solution is hard to achieve, due to the apparent mathematical difficulties. Besides, the modeler may not even be able to formulate an analytical model to capture the system’s behavioral aspects of interest. In contrast, simulation modeling can capture virtually any system, subject to any set of assumptions. This is basically why simulation is utilized to model the complexity of the proposed problem.

Fig. 1 illustrates the structure of agricultural products market in Iran. While simulation models can handle more complex supply
chain environments, such as the effect of middlemen, food industries and exporters, considering these complexities could potentially mask the basic underlying economic tradeoffs in the supply chain, which is the focus of this research. We suggest these additional complexities as topics for future studies.

Lines and arrows specify the relationships between supply chain members. The dashed lines indicate the relationships that are not considered in the present research. The agricultural producers, which are farmers and gardeners, produce the fruits and vegetables. The wholesalers purchase products and sell them to various retailers. The retailers, which are greengrocers all over the city, deal with the final consumers. Meanwhile, importers import fruits and vegetables to fill the gap of product shortages throughout the market. Furthermore, the food industries such as fruit juice producers supply their raw material through wholesalers or importers. Middlemen as the ones who buy things in order to sell them to someone else play effectual and sometimes destructive role all over the market. In addition, Exporters export part of the agricultural products in this structure. Finally, the government develops various policies through monitoring the whole chain continuously. Here, we focus on the government’s import quota policy making.

This study uses a system dynamics modeling approach applied to the fruit and vegetable supply chain for perishable products. It extends the supply–demand–price model of a single market (presented by Sterman, 2000) to a two-stage supply chain.

In this study, the interactions among wholesalers, retailers and customers are modeled throughout a two-echelon supply chain. Fig. 2 illustrates the proposed conceptual model for the study. In this model, according to the investigated market structure, there is a close relationship between farmers and wholesalers, which leads us to consider them as one entity.

The wholesalers supply agricultural products in the first market. The retailers receive the fruits and vegetables from the wholesalers and supply them to the customers in the second market. The retailers play roles of demander and supplier in first and second markets respectively. The + (-) signs at the arrowheads indicate that the effect is positively (negatively) related to the cause.

3.2. Simulation model

Using the conceptual model presented in Fig. 2, a system dynamics simulation model is developed (see Fig. 3). Various levels of the supply chain (shown in Fig. 2) are translated into corresponding stock and flow variables shown in Fig. 3. This model is based on continuous flow of price throughout the supply chain. The supply chain consists of three stages: wholesalers, retailers, and customers.

The time step is considered 1 day in the simulation. It is also possible to run the simulation model based on time step less than or greater than 1 day.

Model assumptions are as follows:

- The supply of retailers in second market assumes to be equal to the minimum amount of their demand and the supply of wholesalers in first market (although the waste has not been considered in the present study, the model is designed flexible enough to consider the waste in the supply chain).
- The product is perishable with the shelf life of one period (it is a logical assumption due to fruits and vegetables’ holding circumstances).

The notation is given in Table 1.

Fig. 3 represents the model of system dynamics simulation designed in Vensim software. Additional details about the simulation procedures are available from the authors.

Model presented in Fig. 3 is concerned with supply, demand and their influences on price.

In system dynamics models, stock variables accumulate or integrate their flow variables; the net flow into the stock is the rate of change for the stock variable. This structure is represented in (1) as an integral equation.

\[
Stock(t) = \int_{t_0}^{t} [\text{inflow}(s) - \text{outflow}(s)] ds + Stock(t_0)
\]  

(1)
where Inflow(s) represents the value of the inflow at any time s between the initial time $t_0$ and the current time $t$.

The mathematical formulations related to the markup and prices are provided as follows.

$$M_i(t) = \int_0^t [CM_i(s)]ds + M_i(0) \quad i = 1, 2$$  \hspace{1cm} (2)$$

$$P_1(t) = \max\{0, C(1 + M_1(t))\}$$  \hspace{1cm} (3)$$

$$P_2(t) = \max\{0, P_1(1 + M_2(t))\}$$  \hspace{1cm} (4)$$

Markup (profit rate) of each supply chain member is defined as a stock variable named $M_i(t)$ according to (2). Price values in first and second market are formulated as non-negative auxiliary variables in (3) and (4) respectively.

### Table 1

<table>
<thead>
<tr>
<th>Notation</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$, $P_2$</td>
<td>Price in the first (second) market</td>
</tr>
<tr>
<td>$M_1$, $M_2$</td>
<td>The mark-up of the wholesaler (retailer) as the stock variable</td>
</tr>
<tr>
<td>$CM_1$, $CM_2$</td>
<td>Rate of change of markup of the wholesaler (retailer) as the flow variable</td>
</tr>
<tr>
<td>$IM_1$, $IM_2$</td>
<td>Indicated markup of the wholesaler (retailer) sensitive to demand/supply balance</td>
</tr>
<tr>
<td>$RB_1$, $RB_2$</td>
<td>Effective term of demand/supply balance on markup of the wholesaler (retailer)</td>
</tr>
<tr>
<td>$B_1$, $B_2$</td>
<td>Demand/supply balance term in the first (second) market</td>
</tr>
<tr>
<td>$SP_1$, $SP_2$</td>
<td>Substitute goods price in the first (second) market</td>
</tr>
<tr>
<td>$S$</td>
<td>Supply of the wholesaler</td>
</tr>
<tr>
<td>$DS$</td>
<td>The retailer’s demand/supply in the first/second market</td>
</tr>
<tr>
<td>$D$</td>
<td>Demand of the final customers</td>
</tr>
<tr>
<td>$RS$</td>
<td>Reference value for $S$</td>
</tr>
<tr>
<td>$RDS$</td>
<td>Reference value for $DS$</td>
</tr>
<tr>
<td>$RD$</td>
<td>Reference value for $D$</td>
</tr>
<tr>
<td>Import</td>
<td>Import amount which is added to supply in the first market</td>
</tr>
<tr>
<td>$ES_1$, $ES_2$</td>
<td>Supply elasticity in the first (second) market</td>
</tr>
<tr>
<td>$ED_1$, $ED_2$</td>
<td>Demand elasticity in the first (second) market</td>
</tr>
<tr>
<td>$s_1$, $s_2$</td>
<td>Sensitivity of price to demand/supply balance in the first (second) market</td>
</tr>
<tr>
<td>$C$</td>
<td>Cost per unit of product</td>
</tr>
<tr>
<td>Inflation</td>
<td>Inflation rate</td>
</tr>
</tbody>
</table>

The mathematical formulations pertaining to effects of supply/demand balance on markup are provided as follows. The basic modeling logic is based on the Sterman (2000) model for a single market.

$$CM_i(t) = \text{delay}[IM_i(t), d] - M_i(t) \quad i = 1, 2$$  \hspace{1cm} (5)$$

$$IM_i(t) = M_i(t) \cdot RB_i(t) \quad i = 1, 2$$  \hspace{1cm} (6)$$

$$RB_i(t) = |B_i(t)|^5 \quad i = 1, 2$$  \hspace{1cm} (7)$$

$$B_1(t) = \frac{DS(t)}{S(t)+\text{Import}}$$  \hspace{1cm} (8)$$

$$B_2(t) = \frac{D(t)}{\min[DS(t), S(t)]}$$  \hspace{1cm} (9)$$

By (5), if there is a discrepancy between the desired ($IM_i(t)$) and actual state of markup ($M_i(t)$), corrective action is initiated to bring the state of the markup variable back in line with the desired value according to (6).

For better representation of the real world, inflation and its effect on price values is taken into account. Because of several delays in the informational transactions in the real world, the effect of demand/supply balance on price is considered with a delay of 1 day. The delay parameters are approximate values obtained based on information provided by experts in Tehran Municipality Organization of Fruits and Vegetables. Delay type 3, which is a system dynamics function that returns a third order exponential delay of the input is applied due to its compatibility.

The effective term of demand/supply balance ($RB_i(t)$) appeared in (6), is defined in (7). By (8) and (9), Demand/supply balance terms are defined as the related demand divided by the whole supply in the pertaining market. By (8), $B_1(t)$ is calculated by dividing $DS(t)$ by the total supply in the first market, which is summation of $S(t)$ and $\text{Import}$.

In modeling of $B_2(t)$, as shown in (9), the final customers' demand ($D(t)$) is divided by the actual supply, which is the minimum of demand and supply in the first market.
The mathematical formulations regarding supply and demand are provided as follows.

\[
S(t) = RS(t) \cdot \text{delay} \left( \frac{P_1(t)}{SP_1(t)} \right)^{ES_1}, d \tag{10}
\]

\[
DS(t) = RDS(t) \cdot \text{delay} \left( \frac{P_1(t)}{SP_1(t)} \right)^{ED_1}, d \cdot \text{delay} \left( \frac{P_2(t)}{SP_2(t)} \right)^{ES_2}, d \tag{11}
\]

\[
D(t) = RD(t) \cdot \text{delay} \left( \frac{P_2(t)}{SP_2(t)} \right)^{ED_2}, d \tag{12}
\]

By (10), the actual amount of wholesalers' supply, \(S(t)\), is obtained by considering the effect of the price \(P_1(t)\) and substitute goods price \(SP_1(t)\) in the first market. \(ES_1\) adjusts the intensity of the mentioned effect. This formulation is consistent with the formulation of a single market by Sterman (2000).

The effect of price on supply and demand is considered with a delay shown as \(d\) parameter in the formulation. While \(d\) parameters are shown with the same notation, the values are different for each equation.

Eq. (11) is the most related equation to the supply chain. According to the model assumptions, the demand of the retailer in the first market equals the supply of the retailer in the second market. \(DS(t)\) that models both supply and demand of the retailers is calculated by multiplying the impact of both markets' prices by the reference value \(RDS(t)\). Thus, the demand and the supply of the retailers in the first and second market are affected by the prices in both markets.

Similar to (10), the Eq. (12) shows the effect of prices on the customers' demand. Final customers' demand elasticity, \(ED_2\), adjusts the intensity of the mentioned effect.

The mathematical formulations related to reference values for supply and demand are provided as follows.

\[
RS(t) = \text{smooth}[DS(t)], s \tag{13}
\]

\[
RDS(t) = \text{smooth}[D(t)], s \tag{14}
\]

The smooth function that is commonly used to model averaging in a process, is used in Eqs. (13) and (14) with the aim of averaging the demand in each market. This models the general behavior of wholesalers and retailers on adjusting their supply according to the demand. By (13), \(RS(t)\) which is the reference value for the wholesalers' supply, is obtained by averaging the retailers' demand \(DS(t)\). By (14), the same equation is modeled in the second market.

### 4. Scenario-based analysis and validation

We applied the model in Tehran's fruits and vegetables market. Cherry was considered as a perishable fruit for analysis. The specific characteristics of the system are as follows. Inflation rate per year is 18% based on the information presented by IRI Central Bank (2012). The Iran's total cherry production is 255,500 tons in 2010 (FAOSTAT, 2012). Besides, 3292 tons of the production has been exported. The remaining amount is supplied in local market of Iran; but this study investigates the market of Tehran (the capital of Iran). Therefore, we estimate the total supply in the Tehran's market using population and consumption coefficients. Finally, the average demand of Tehran's consumers is estimated to be 3500 tons per week. Average production cost (per kilogram) is 1.6 dollars. Substitute goods price in the first and second market are 2 and 2.5 dollars, respectively. The detailed supply trend in the market is obtained from expert judgment in the validation periods equals to 14 weeks from May 20 to August 19, 2010.

The quantitative validation is conducted in two steps. First, the parameter values are estimated using 2010 data. The calibration and parameter estimation results are shown in Tables 2 and 3, respectively. Then, the simulation model runs and the results are compared with 2011 data (see Fig. 4).

While supply elasticity and sensitivity of price to demand/supply balance are some positive values, demand elasticity is a negative value according to the modeling logic. The calibration has been done using AnyLogic™ software (www.anylogic.com).

Fig. 4 illustrates the comparison of the simulation outputs against the actual data of the wholesaler's and retailer's price for the cherry in 2011. The comparison shows that the model is quantitatively validated.

In addition to the quantitative validation, the model is also validated qualitatively. In this case, some realistic scenarios are defined based on what happens in the real world. The results gained from these scenarios provide several insights. These scenarios can also be used for the validation of the proposed model. We have checked the model's validity by conducting validation tests suggested by the system dynamics literature (Sushil, 1993; Barlas, 1994; Sterman, 2000). The qualitative validation test is done by the method called “behavior reproduction test” (Sushil, 1993). Before testing the behavior accuracy, it is necessary to test the validity of the structure (Barlas, 1994). The structure test has been done by assessing the validity of the model equations individually by comparing equations with the related literature and available knowledge of the real system.

The following scenarios are based on numerical examples to conduct the qualitative validation.

#### 4.1. Scenario 1 – increase in the final customers' demand

Sudden increase in fruit price in both levels of supply chain is occurred when sudden increase in demand of fruit happens.

<table>
<thead>
<tr>
<th>Date</th>
<th>Market 1 price ($)</th>
<th>Market 2 price ($)</th>
<th>Calibration results</th>
<th>Actual dataa</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 20</td>
<td>2.854</td>
<td>3.262</td>
<td>7.940</td>
<td>8.236</td>
</tr>
<tr>
<td>May 27</td>
<td>2.125</td>
<td>2.627</td>
<td>4.650</td>
<td>5.379</td>
</tr>
<tr>
<td>June 3</td>
<td>1.87</td>
<td>1.935</td>
<td>3.322</td>
<td>4.468</td>
</tr>
<tr>
<td>June 10</td>
<td>1.796</td>
<td>1.923</td>
<td>2.819</td>
<td>3.960</td>
</tr>
<tr>
<td>June 17</td>
<td>1.778</td>
<td>1.923</td>
<td>2.633</td>
<td>3.638</td>
</tr>
<tr>
<td>June 24</td>
<td>1.779</td>
<td>1.923</td>
<td>2.582</td>
<td>3.046</td>
</tr>
<tr>
<td>July 1</td>
<td>1.783</td>
<td>1.923</td>
<td>2.566</td>
<td>2.728</td>
</tr>
<tr>
<td>July 8</td>
<td>1.789</td>
<td>1.846</td>
<td>2.551</td>
<td>2.692</td>
</tr>
<tr>
<td>July 15</td>
<td>1.796</td>
<td>1.615</td>
<td>2.526</td>
<td>2.429</td>
</tr>
<tr>
<td>July 22</td>
<td>1.802</td>
<td>1.531</td>
<td>2.478</td>
<td>2.393</td>
</tr>
<tr>
<td>July 29</td>
<td>1.803</td>
<td>1.531</td>
<td>2.409</td>
<td>2.408</td>
</tr>
<tr>
<td>August 5</td>
<td>1.797</td>
<td>1.764</td>
<td>2.338</td>
<td>2.705</td>
</tr>
<tr>
<td>August 12</td>
<td>1.842</td>
<td>1.899</td>
<td>2.457</td>
<td>2.825</td>
</tr>
<tr>
<td>August 19</td>
<td>2.073</td>
<td>2.157</td>
<td>3.225</td>
<td>3.656</td>
</tr>
</tbody>
</table>

(e.g. in the days before the New Year holiday in which people tend to purchase more fruits for the ceremonies). The reference value for final customers' demand ($RD(t)$) is increased by 50 tons from time 60 to 80. Fig. 5 illustrates the results of scenario 1.

According to Fig. 5, the increase in customer's demand not only leads to an increase to retailers' supply and demand, but also an increase in wholesalers' supply (Fig. 5A). This eventuates in product's price augmentation. Even though price increases after a rise in demand on the 60th day (Fig. 5D), with a delay, customers' demand decreases when this price exceeds the price of the substitute goods (Fig. 5B). Thus, retailers have to reduce their markup (Fig. 5C) and finally, price will reach a stable state.

4.2. Scenario 2 – decrease in the wholesalers’ supply

With sudden decrease in supply, for example due to climatic changes such as drought, which is probable in Iran, sudden increase is observed in the prices in both levels of supply chain. On the other hand, over the specified period, because of such increase in the price, the pertaining demand will decrease in order to control the impact of the rise in the price. This scenario considers a
90% decrease in the reference value for the supply of wholesalers \((RS(t))\) from time 60 to 80. Fig. 6 illustrates the results of scenario 2.

Fig. 6 indicates that after a reduction in supply on 60th day (Fig. 6A), although wholesalers sell the product with higher markup (Fig. 6C), the retailers cannot increase their markup immediately. This occurs because they decrease their supply with a delay. However, when the price rises with a delay (Fig. 6D), the demand decreases (Fig. 6B) and thus the wholesalers no longer are able to increase their markup so as the retailers (Fig. 6C). These patterns continue until the price values become stable.

Followings are other situations defined as practical scenarios for analysis:

- A decrease in substitute goods prices.
- An increase or decrease in the production costs: a sudden increase in production cost leads to a decrease in demand in each level.
- A changes in supply or demand elasticity.
- A changes in the sensitivity of price to the demand–supply balance.

Elasticity and sensitivity parameters were analyzed in sensitivity analysis and it revealed that changes in these parameters would intensify changes in the values of other variables. The detailed results for these scenarios are not presented due to space limitations, but are available from the authors.

The defined scenarios not only provide detailed analyses of the model, but also help to indicate that the model is valid based on the behavior reproduction method. In reality, a combination of scenarios could create various trends in supply and demand that finally influence the price. Next section seeks to conduct a multi-objective analysis for import quota policy making in the situation in which some of the previously mentioned scenarios happens in the market.

5. Multi-objective results, analysis and discussion

An import quota sets a maximum permissible volume or value of a product that can enter a country during a particular time. The import quota limit is normally declared before the beginning of this time. Import quotas can be administered on a “first-come, first-served basis” by allowing imports until the quota ceiling is reached and then closing the border to further imports (Reinert et al., 2008).

Governments often use import quotas to protect domestic producers from import competition or to encourage domestic production. Different states responding to the amounts of import are \(x_1, x_2 \in [0, 100, \ldots, 500]\) regarding to the historical data presented by the government and different states relating to import change time (the time in which the import quota changes from \(x_1\) to \(x_2\)) are obviously \(importChangeTime \in \{1, 2, \ldots, 12\}\), indicating the month number of a year.

In reality, several events might occur simultaneously in the market. Prior to providing an import quota policy, other parameters are estimated according to the expert judgment and history data. As a result of the future analysis, a scenario is defined that sets a 40% decrease in the supply of wholesaler on the 4th month and 40% increase in the customers’ demand on the 8th month.

The supportive role of the government in supply chain management of fruits and vegetables has two sides: supporting domestic producers and supporting final consumers. The first goal is achieved by maximizing the wholesalers’ markup (which consequently maximizes the farmers’ markup). The second goal is achieved by minimizing the price mean and variation in the second market. These different goals are analyzed in a multi-objective approach.

The multi-objective formulation would be as follows:

\[
\begin{align*}
\text{Min } Z_1 &= \sum_{t=1}^{n-1} (\text{price}_{t+1} - \text{price}_t)^2 \quad \text{(15)}\\
\text{Min } Z_2 &= \frac{\sum_{t=1}^{n} \text{price}_t}{n} \quad \text{(16)}\\
\text{Max } Z_3 &= \frac{\sum_{t=1}^{n} \text{markup}_t}{n} \quad \text{(17)}
\end{align*}
\]

While objective (15) aims to obtain a smoothed price in the market by minimizing the price variation, objective (16) minimizes the mean of price. As in Karimi-Nasab and Konstantaras (2012) and Karimi-Nasab and Ghomi (2012), we take into account the variation in form of sum of the squared difference of subsequent prices. Objective (17) deals with maximizing the mean of the wholesaler’s markup. This objective indicates the supporting role of the government for agricultural producers.

Fig. 7 shows the surface plot of price variation vs. price mean and markup. The surface plot is developed by changing the

![Fig. 6. Scenario 2 outputs (decrease in the wholesalers’ supply). From top to bottom and from left to right: A, B, C, D.](image-url)
upper/lower bound of two objectives and finding the value of the third objective corresponding to the best state. Applying the methodology proposed by Messac et al. (2003), the Pareto-frontier is built based on the 81 non-dominated solutions found.

The surface plot (Fig. 7) along with the government’s three-dimensional utility function as preference information is used to select a subset of Pareto solution for the import quota policy. The utility function is a mathematical expression that attempts to model the decision-makers’ preferences. In this analysis, the government’s utility function represents the relative importance of the three objectives.

Nevertheless, the trade-off between different objectives could be better presented by contour plot. The contour plots shown in Figs. 8–10 give a representation of the trade-off solutions. Fig. 8 depicts the contour plot of markup vs. price mean and price variation.

The contour plot shows the trade-off between price mean and price variation. The values specified on the lines indicate the pertaining markup values. Fig. 8 demonstrates that if the decision maker expects to have a lower price variation, he ought to accept a higher price mean. This behavior changes through different values for the markup. Considering the line with the markup value of 15%, a threshold is observed for the price variation. While a price variation beneath 0.5 causes a steep gradient in price mean, setting the price variation value over 0.5 will not have such an effect. Higher values of markup such as 25% make the decision maker to accept higher values for price mean and variation. Besides, it limits the decision makers’ scope of changing priorities of objectives.

Fig. 9 illustrates that if the decision maker expects to have a lower price mean, he ought to accept a lower markup. For specific price variation value of 0.2, if the decision maker expects a lower value for price mean to satisfy final customers, a threshold is observed for the price mean. Lowering the price mean up to 3 (the threshold) will be achieved without setting a lower value for markup (the government is willing to support the producers by allowing higher markups). However, setting the price mean value beneath 3 causes an unwanted reduction in markup.

Fig. 10 demonstrates that if the decision maker expects to have a higher markup, he ought to accept a higher price variation which is not satisfying. This behavior is observed in different values of price mean. For specific price mean value of 3, it is observed that the trade-off is meaningful for only some parts of Pareto frontier line. That is, for markup values between 10 and 20 and price variation values between 0.6 and 0.8, changing the preference between markup and price variation results in deterioration in both objectives. Therefore, it is not logical for the decision maker to accept this range for markup and price variation when the price mean is set to be 3. In addition, different patterns of the contour lines for different values for the price mean indicate the high sensitivity of price mean in the multi-objective analysis. This clearly shows that the multi-objective analysis is a nonlinear non-convex problem due to the fact that the contour plot is neither linear nor convex.

The intersection of the government’s two-dimensional utility function and the contour plot is indicative of the best import quota policy. The obtained Pareto frontier contour plot is proposed to support decision makers for quick import quota policy making in the case of a change in government’s priorities.
6. Conclusion

This study proposed a simulation model to investigate the relationships in fruits and vegetables supply chains using system dynamics approach. It is useful as a high-level tool to analyze the interactions of supply, demand and price. The model was validated by means of behavior reproduction test. Our observation shows that applying the best import policy helps to reduce the undesired price changes in case of different scenarios for demand and supply. Thus, it may prove useful to policy makers especially governmental authorities dealing with a wide spectrum of strategic fruit and vegetable supply chain management issues. A multi-objective analysis was conducted to empower the system dynamics model throughout trade-off solutions for import quota policies obtained in the form of Pareto Frontier. The specified thresholds observed in this study provide an insight for governmental decision makers to have better understanding of the trade-offs between three objectives: price mean, price variation and markup.

Combination of agent-based simulation and system dynamics is suggested for future research. In addition, this model can be expanded to take into account further market characteristics such as the interventions of middlemen. Even though the model is useful to study relationships between supply chain members, the model does not take into consideration detailed inventory considerations, transportation and warehousing. These are topics for future research.

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