From Generic to Optimally Calibrated System Dynamics Models: An Application in Agricultural Value Chains

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Model calibration and validation are crucial steps to establish the reliability of mathematical models, especially when the modeling purpose is policy and scenario analysis for a real-world case. In this paper, adaptation and automated optimal calibration of a generic system dynamics model to a real-world case and its validation are presented for the capacity, supply, demand, and price dynamics of an olive oil value chain.

In recent years, despite the increasing population of olive trees and olive oil supply in Turkey, consumer prices for olive oil have unexpectedly increased (Figure 1).

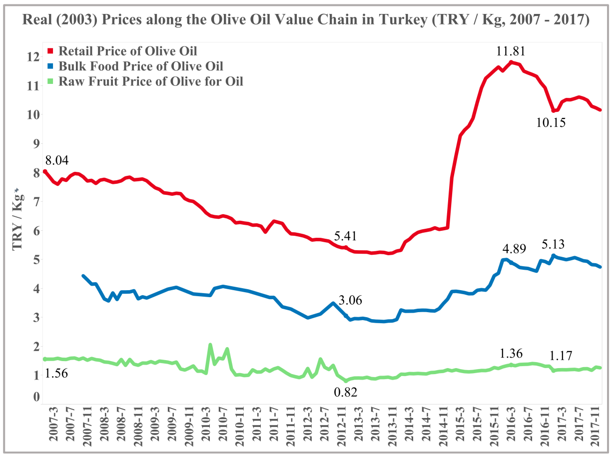

Figure 1 – Prices along the Olive Oil Value Chain in Turkey

Our dynamic hypothesis behind this phenomenon 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, and different price levels along the value chain affect each other in feedbacks and nonlinear ways (Figure 2).

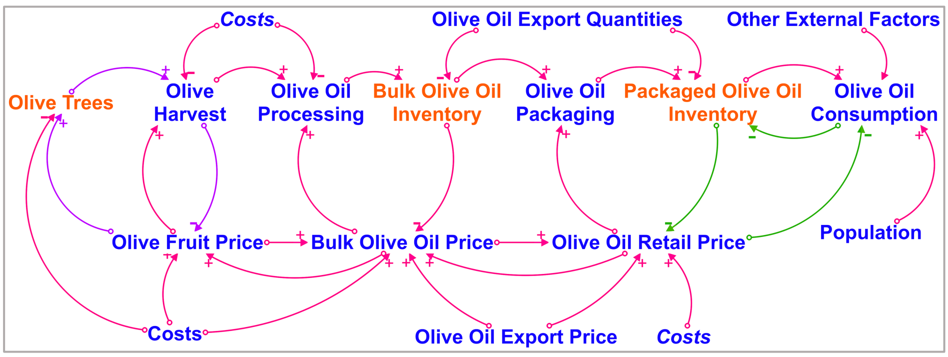

Figure 2 – Causal Loop Diagram for the Olive Oil Value Chain

The major feedback loops shown in the causal loop diagram are: (i) the reinforcing loops among different price levels, (ii) the balancing loop adjusting Olive Trees, which represents the behavior of the long-term supply curve, (iii) the balancing loops adjusting the Bulk Olive Inventory and Packaged Olive Oil Inventory levels, which represent the behavior of the short-term supply curve, and (iv) the balancing loop adjusting the Olive Oil Consumption level, which represents the behavior of the demand curve.

Even though there exists a vast literature on system dynamics modeling applications for real-world problems, the calibration and validation steps of these applications are not widely reported. Apart from the contribution of our work to system dynamics model calibration and validation literature, one important contribution of our study is building a unique system dynamics model for agricultural value chains incorporating the following three characteristics simultaneously: (i) including both supply chain and value chain structures at the national level, (ii) considering the four major market elements; price, demand, supply, and capacity, endogenously, (iii) considering complex nonlinear and feedback relationships among the price levels in different stages of the agricultural value chain.

In line with our modeling purposes, a generic model for the olive oil value chain was built with nine interacting modules. The relationships among these modules are depicted in Figure 3. 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. In 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 olive fruit to the packaged olive oil.

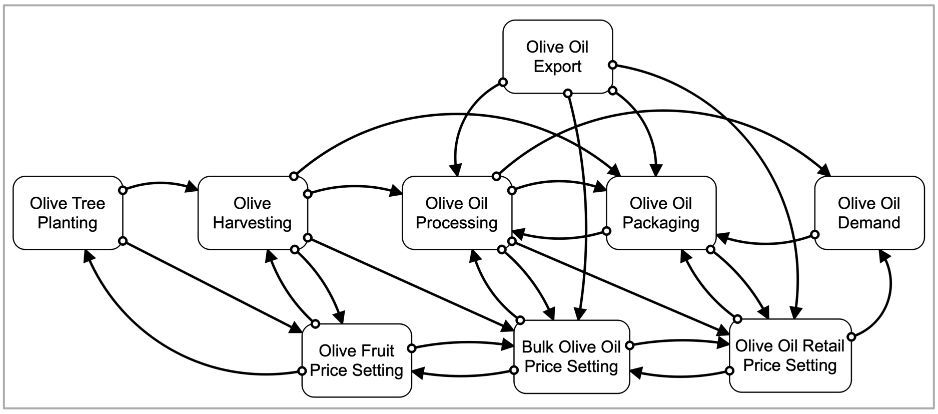

Figure 3 - Modules of the Olive Oil Value Chain Model

In order to see the behavior of the variables of the generic model (before the parameters are calibrated according to a specific historical data set), parameter values are set according to an approximate equilibrium for a given market size, and exogenous variables are set to constant values. When model results are examined for the endogenous variables, most of them exhibit an oscillating behavior from one harvest year to another (Figure 4).

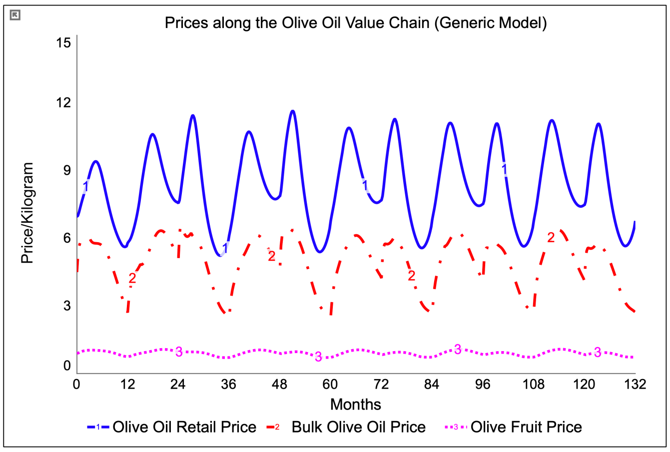

Figure 4 – Generic Model Outputs

In order to adapt the generic model to our real world case of Turkish olive oil value chain, a series of Model Formulation Adaptation Procedures are implemented which can be listed as 1 - Building adaptive structures, 2 - Explicit reformulation of closed-form equations, 3 - Building asymmetric adjustments, 4 - Differentiating perceptions of different parties, 5 - Aggregation / disaggregation of related variables, 6 - Different formulations of functions for similar purposes, and 7 - Defining minimum / maximum bounds. Then, the Automated Calibration Procedure is followed with the goal of "minimizing the sum of the squared differences between the model-generated values and historical data.” During parameter setting and automated calibration, a Model Calibration Checklist is followed, which is prepared as a compilation of rules and guidelines given in Barlas (1996), Oliva (2003), and Sterman (2000). Meanwhile, relevant Model Validation Tests (Barlas, 1996) are performed for the credibility of the model results. Finally, the calibrated and validated model is obtained; the model run results for the price levels along the olive oil value chain in Turkey can be seen in Figure 5.

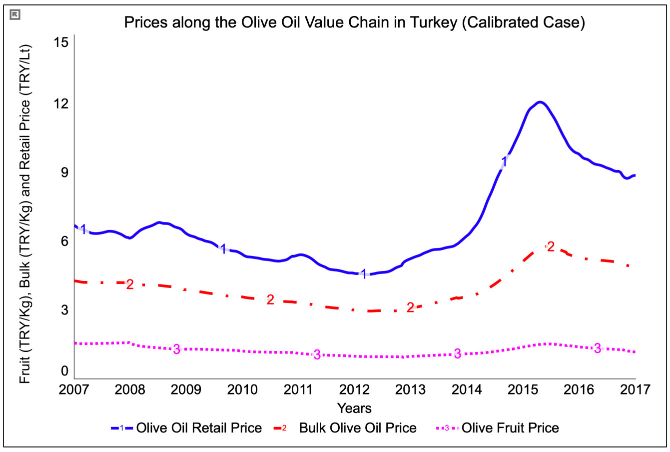

Figure 5 – Calibrated Model Outputs

In order to investigate the effect of optimal parameter calibration on the behavior reproduction, we build and run another model, which we call an “intermediary” model with the following properties: (i) it has exactly the same structure as the generic olive oil model for each and every equation (ii) all historically available and known exogenous variables related to the Turkish case are fed into the model as inputs, (iii) yet, no calibration is performed, all unknown parameters are exactly the same as the generic olive oil model parameters. The behavior of the intermediary model is given in Figure 6.

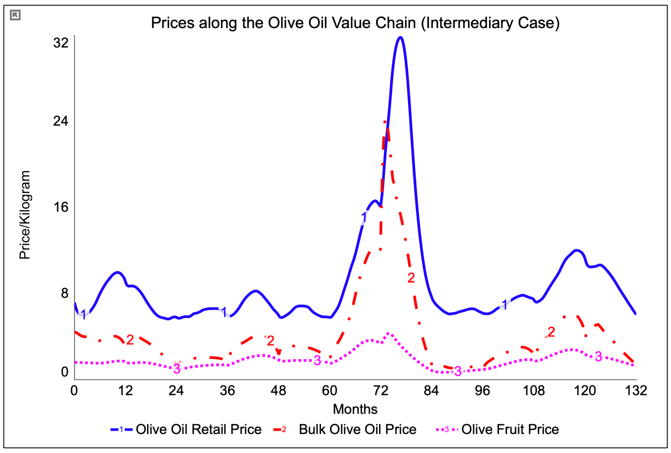

Figure 6 – Intermediary Model Outputs

When the structure and the behavior of all three models – generic, optimally calibrated and intermediary – are considered, the theoretical and practical implications of this study can be summarized as follows: (1) While preserving its generic and theoretical causal structure, it is possible to optimally calibrate a medium-large generic system dynamics model for a real-world case, (2) Even though the causal structure is preserved, the dynamic behaviors of the generic model and optimally calibrated model can be quite different, which implies the significance of model calibration, (3) Rather than being considered as two separate, sequential procedures that must be completed in order, model validation tests and optimal parameter calibration models should be considered as integrated processes that must be performed simultaneously, (4) Even in data-poor problem environments, as in our case, the modelers should seek optimal calibration possibilities before policy analysis. Simulation results show that even though the causal structures of three model versions are the same, behavior patterns are highly dependent on parameters that are unknown and need to be calibrated. Policy recommendations derived with arbitrarily set parameters may have quite wrong implications for the policymakers.

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