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The Maple Sap Products Industry in Quebec: An Economic and Production System Dynamics Model

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Abstract

The SD model expounded in this paper characterizes the nonlinear and dynamic behavior exhibited in maple sap production, and the potential hazard of long feedback delays involved in fixed asset investments supporting sap collection and syrup production. Developed following the structure introduced in Meadow's (1970) dynamic commodity cycle model, this model is adapted to the specifics of maple syrup production, and integrates structural elements of price expectations, supply response, demand substitution, and inventory fluctuation. As with most commodity production, maple sap collection and syrup production are subject to production, price, and stock pileup risks. All industry participants are subject to the uncertainty associated with long time delays in the formation of price expectations, in the adjustment of the supply response, seasonal production, and the demand for exports. Illustrative simulation results are presented. Extensions to the current works are outlined in the conclusion.

Key Words: maple syrup, system dynamics, price expectations, feedback.

Introduction

The maple sap products industry has little in common with its romantic origins still perceived by consumers. In today's marketplace industry, participants must coordinate, manage dependencies, obtain information about demand and supply conditions in international markets, and strive to bring the best quality product to consumers' tables. The industry has become more responsive to consumers through efforts such as the introduction of quality grades for the syrup as a quality differential mechanism.

As with most commodities, maple syrup production has been subjected to production, price risk, inventory buildups, and other uncertainties. These latter elements of uncertainty include misperception in feedback among producers regarding the "expectation-supply response connection." This uncertainty is reflected in large swings in inventory, stock buildups, and other typical dynamic elements of behavior observed in commodity production (Meadows 1970; Sterman 2001). Inventory buildups became an important problem during the 1979-1981 period. Additionally, since 1988, the industry has adopted technology and management practices that have contributed to more than 50% growth in production volume. Because of these factors, the history of the industry in Quebec since the 1970s includes numerous cycles of excess supply and inventory buildups, leading to episodes of production overshot relative to the market absorption capacity as well as price collapses.

The objective of this paper is to report on the design of a system dynamics (SD) model that integrates the structural elements of supply response, demand substitution, and inventory fluctuation in the production of maple sap products in Quebec. Aside from government monographs (MAPAQ 1996,1999), descriptive technical statistics reports (Gilbert et al. 2000), and case studies (Dicaire 1985), there is a paucity of formal economic and quantitative modeling of maple syrup production. The SD modeling approach is appropriate given the nonlinear and dynamic behavior exhibited in production, and the long feedback delays involved in the investment of the fixed assets necessary to support production.This paper is structured as follows. The following section provides a brief background of the production and industry. Using this background information, a dynamic hypothesis is presented using an influence diagram as a means to describe the economic and production behavior of the industry. The influence diagram sets the stage for the model development. Details are provided on the development of the model and data source. Simulation results looking at the potential for growth in export markets are presented to illustrate the potential of the model, and a conclusion follows.

Industry Background

The product at the origin of the maple products industry is the sap of a tree. Maple syrup is the main product extracted from the sap. The evaporation of 34 liters of maple sap is necessary to obtain 1 liter of syrup. Other maple sap products are obtained through further evaporation and sometimes stirring; these products include maple butter, maple taffy, soft maple sugar, hard maple sugar, and granular sugar.

The maple sap products industry in Quebec sells about $120 million annually worth of maple sap products. Quebec production represents approximately 70% of the industry's total North American output, and 90% of Canada's production. Quebec is the largest producer of

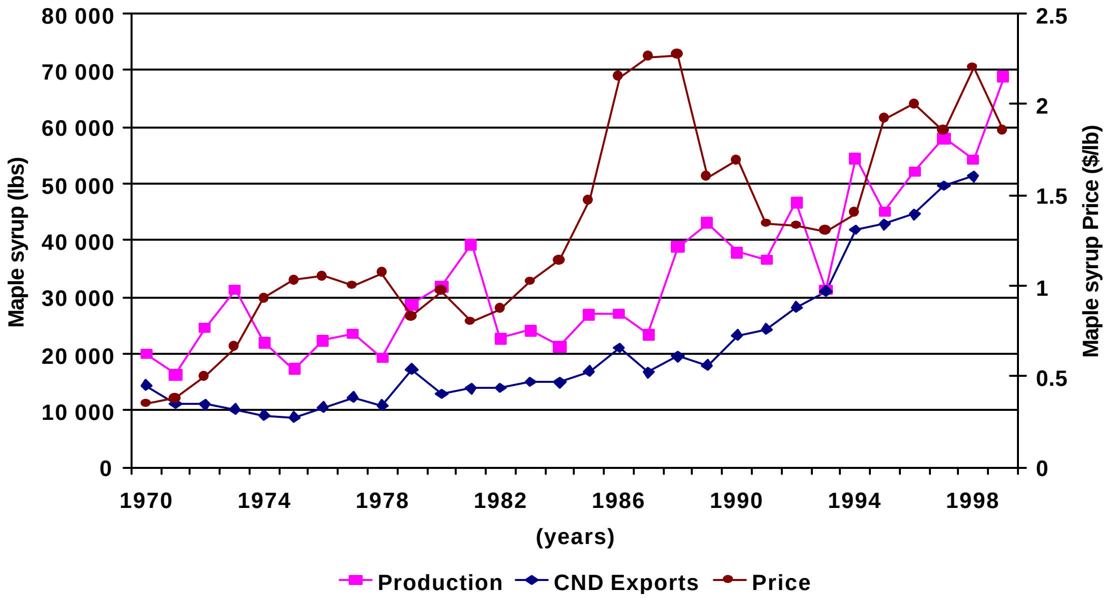


Figure 1 Production, exports, and price trends - 1970-1999

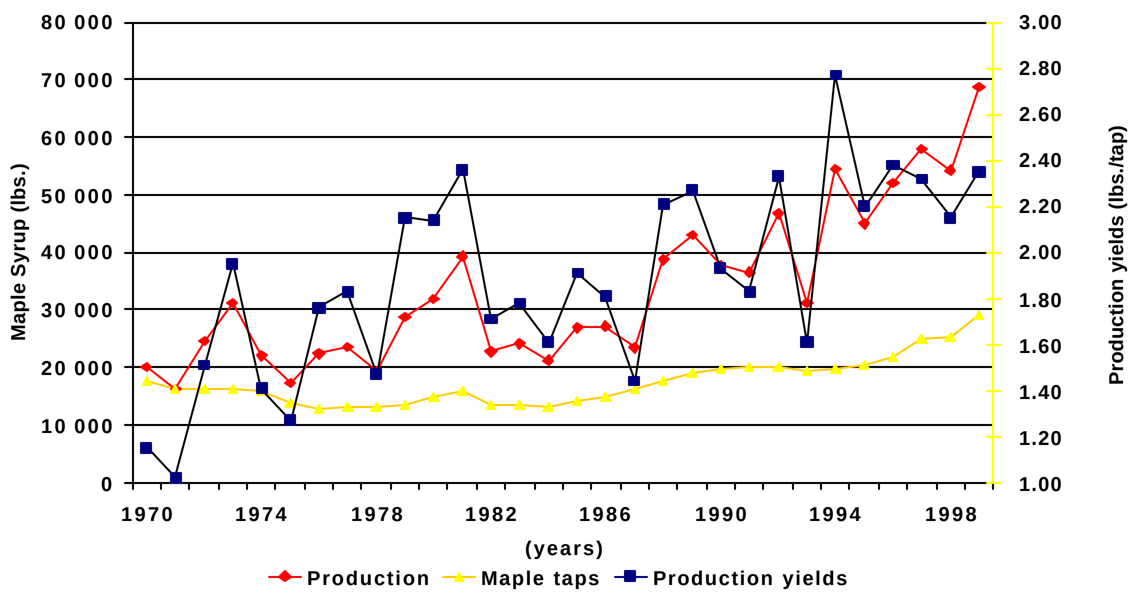


Figure 2 Production, maple taps, and yield trends - 1970-1999

maple sap products, and while domestic markets absorb a fair share of this production, domestic output far exceeds local demand. Roughly 90% of production is destined for export markets. Bulk maple syrup is the most important maple sap product exported. In fact, between 1993 and 1999, exports have increased by 115% percent. The bulk of exports is sold to the United States, and, as well as to 32 other countries, including Germany, France, Australia, Japan and Taiwan. Exports to the United States show a moderate steady upward trend, while exports to other markets tend to fluctuate from one year to the next.

As seen in Figure 1, the trend in exports has increased dramatically since 1990. Maple syrup production has dramatically increased as well. The production volume and price trends clearly show opposite movement overtime. Prices tend to fall when production soars and vice versa. Interestingly, both prices and production appear to cycle around an upward trend.

In Figure 2, the number of maple taps shows a moderate upward trend since the mid-1980s. Aggregate gains in productivity arise from this trend as well as from improved management practices and widespread adoption of the tubular sap collection technology, the "SYSVAC." This gain in productivity can be seen from the rising trend in yields. The production of syrup also is subject to production risks, as is seen from the jigsaw pattern from one year to the next. This pattern is highly correlated with production output and the evidence of ubiquitous production risk.

Hypothesis of the Maple Syrup Production Behavior in Quebec

The influence diagram presented in Figure 3 consists of two balancing feedback loops labeled B1 and B2. The balancing loop labeled B1 depicts the structure of supply response, and the balancing loop labeled B2 represents the structure of demand substitution.

The balancing loop B1 comprises three variables, namely the price of maple syrup, the expected price, and the supply response. The relationship between the price and the supply response follows the principles of neoclassical economic theory as it relates to supply. As the price rises (falls) producers tend to expand (contract) production. This can be accomplished either by investing (disinvesting) in productive capacity or by using (idling) excess capacity. An increase (decrease) in the supply response leads, with a time delay, to an increase (decrease) in inventory. A growing (shrinking) inventory would result into a downward (upward) price pressure, assuming everything else remains constant. This in turn leads to a lower (higher) expected price for producers.

It is important to note that long time delays are part of the structure of the supply response feedback loop (B1). The annual production cycle means that producers have roughly a year to form price expectations and then, after an investment decision is made, additional time is needed to execute the adjustment and to bring this capacity online. After resources (in the form of fixed assets) are committed to production capacity, these resources may contribute to excess production capacity if producers over-expand, relative to the market absorption capacity, or if the price takes a downward turn. In the case of over-expansion, fixed production costs per unit will be higher, and in the case of the price drops, producers may keep production going over several crop seasons in hope for higher prices and further exacerbating excess supply. The outcome is inventory buildups. The supply expansion can have a lasting effect that extends through time due to asset fixity and other government programs designed to ease producer cash flow.

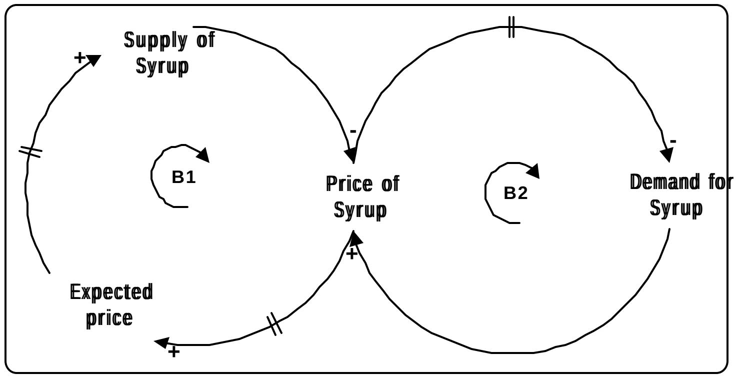


Figure 2 Influence diagram of maple syrup production dynamics

The balancing loop B2 represents the structure of demand substitution. As seen previously, an increase (decrease) in the syrup inventory leads to a decrease (increase) in price. Following economic theory, a lower (higher) price makes the product more (less) attractive for consumers, relative to substitutes. An increase (decrease) in demand will deplete (maintain) the inventory. As a result, a lower (higher) inventory results in a higher (lower) price.

The influence diagram described above does not account for the role of government or of the producers' federation that could play a role in influencing the extent of the supply response, the management of the maple syrup inventory, and the stimulation for exports. These aspects are to be further developed in subsequent work.

Dynamic Model of Maple Syrup Production

The SD model as seen in figure 4 was designed using the Powersim® software. The model structure is adapted from the one developed by Meadows (1971) to study dynamic commodity cycles. Although adjustments to the original model were conducted to account for the specifics of maple syrup production, the economic and physical stock and flow variable interactions of this model's structure are similar.

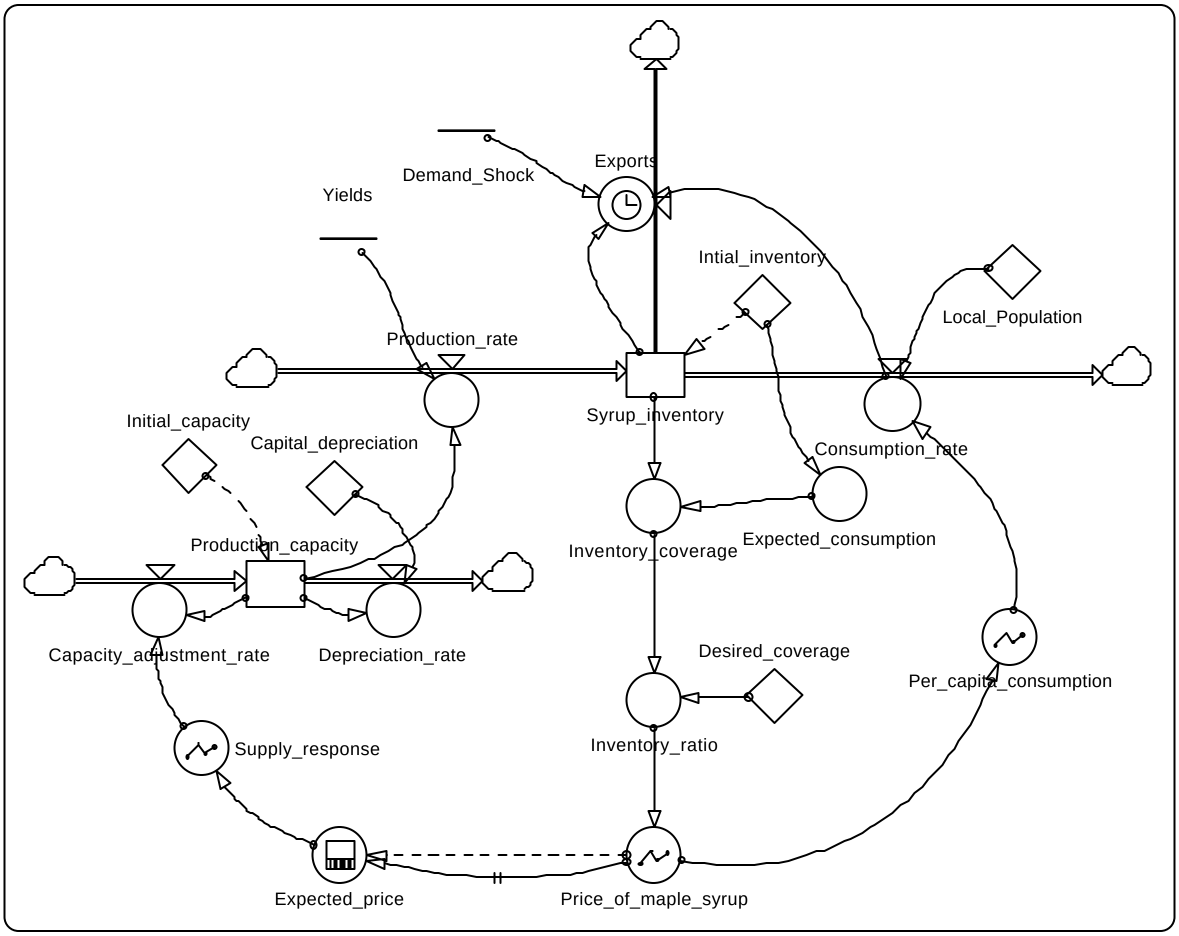


Figure 4 Stock and flow diagram of maple syrup demand substitution, supply response, and inventory

Adjustment in the stock variable syrup inventory, denoted Ö, is augmented by the production rate (*r*). The syrup inventory is diminished by the consumption rate (*c*) on the local market, and exports (*x*). This relationship is captured in equation (1)

(1) $$\Phi = \Phi_0 + \int_0^t (r - c - x)\,\mathrm{d}t\,.$$

Equation (2) calculates the consumption rate that is the result of the per capita consumption, denoted Ë, multiplied by the local population (*l*),

(2) $$c = \Lambda\, l.$$

Equation (3) calculates exports as a residual of the inventory minus the consumption rate multiplied by è, a demand shock,

(3) $$x = (\Phi - c)\boldsymbol{q}.$$

The production rate r, as calculated in equation (4) augments the inventory and is the result of the production capacity (Ù) measured in maple taps multiplied by the maple syrup yield per tap (*ã*)

$$(4) \qquad r = \Omega\, \boldsymbol{g}.$$

Fluctuations in the maple syrup inventory change the inventory coverage (v). The inventory coverage is the quantity of maple syrup that defines the equilibrium with expected consumption (m). This is calculated in equation (5)

$$(5) \qquad v = \Phi / m.$$

A change in the inventory coverage influences the inventory ratio (w). The inventory ratio is calculated by dividing the inventory coverage by the desired coverage (*ä*) as in (6)

$$(6) \qquad w = v / \boldsymbol{d}.$$

The inventory coverage drives maple syrup price movements. The price change influences price expectations. Producers expectations are calculated using exponential smoothing (Weiner 1966), also known as the ‘adaptive’ price expectation model (Arrow and Nerlove 1958; Nerlove 1958). This method is frequently employed in SD models to account for the time delay in the transmission of information “until persistent or stable delays are detected” (Lyneis 1980:435). Technically, the adaptive price expectations assume that recent information has more influence on the formation of price expectations than does less recent information. The time expectation for the maple syrup price (ô = 1 / t) is a time span that producers are considering for making an adjustment decision. Thus the integral component in (7) divides the difference between the current price (P) and the exponential smoothed maple syrup price in the previous period (t - 1), that is (P_0), over a time span (ô) necessary for producers to build their maple syrup price expectation (EP). The adaptive maple syrup price expectation in the model is calculated as follows

$$(7) \qquad \mathrm{E}\,P = P_0 + \int_0^t \boldsymbol{t}\ (P - P_0)\,\mathrm{dt}..$$

The price expectation is linked to the desired production capacity (number of maple taps) by means of a table function.

The production capacity is the result of producer upward (downward) adjustments as a response to economic incentives, that is, by the expansion of production when conditions are favorable. In the event that economic conditions take a downturn, production could continue because assets, in the form of equipment, are specific and assumed not transferable to alternative use. The maple taps acquisition rate (a) in (8) incorporates the maple taps acquisition delay ($á_d$) associated with the difference between the desired maple taps ($Ù_d$) and the current level of maple taps (Ù). The acquisition delay explicitly takes into account the time necessary for resources acquisition associated with the adjustment of maple taps at the desired level, given by

$$(8) \qquad \frac{\mathrm{d}a}{\mathrm{dt}} = (\Omega_d - \Omega) / \boldsymbol{a}_d$$

The adjustment in the level of maple taps is stated in equation (9)

(9) $$\Omega = \Omega_0 + \int_0^t (a - (y/t))\, dt,$$

where a is the adjustment in the number of maple taps as calculated in (8), and y is the depreciation rate and t is the expected useful life of the equipment measured in years.

The maple syrup price also is used to determine consumer demand on the domestic market using a table function. This table function is based on econometrically estimated relationship between the price of maple syrup and the per capita consumption. This table function calculates the consumption rate (c) seen in (2).

Data Sources and Model Calibration

The data employed to calibrate the model were obtained from publicly available time series data, coefficients, and industry sources. There are two state variables in the model, namely, the maple syrup inventory and the production capacity. These initial levels constitute the baseline figure for the model. Table 1 summarizes the variable and parameter name, the value, and the source for the state variables and the parameters of the model.

Table 1 Model state variable equilibrium (or initial) specification

Symbol	State variables	Specification	Source
Ö	Initial Maple syrup inventory (kiloliters)	16,599	Industry
Ù	Initial production capacity (taps)	21,078	Calibrated

Table 2 contains the list of parameters that are included in the model, their calibrated specifications, and their sources.

Table 2 Model parameter specifications

Symbol	Parameters	Specification	Source
ã	Production yield (liter / maple taps)	0.74	Mean trend
v	Desired inventory coverage (years)	1	Assumption
á*d*	Adjustment of maple taps (years)	2	Industry
y	Useful life of capital (years)	7	Industry
ë	Local population (individuals in thous.)	7,139	BSQ

Three table functions are specified in the model. First in Figure 5, the inventory coverage in the model is a means to approximate the relative scarcity of maple syrup with respect to the expected consumption equilibrium level in a given year. This information is transmitted to determine the inventory ratio relative to the period of desired coverage. Variations in the inventory ratio directly influence the price of maple syrup in the model. Industry sources have indicated that the equilibrium price for the crop year 2000 crop was $2.00 for an output level of 60,000 pounds. The formula employed to determine the marginal price that follows a change in the inventory ratio is $0.10 per 5,000 pounds of maple syrup. The minimum price that would be set without causing massive pain to producers is $1.60 per pound for production output of 80,000 pounds. The equilibrium production level in inventory is used to calibrate relative coverage in the model. The inventory ratio exercises expansion and contraction pressure on the price of maple syrup. A relatively higher inventory ratio means less scarcity and thus lower prices, and

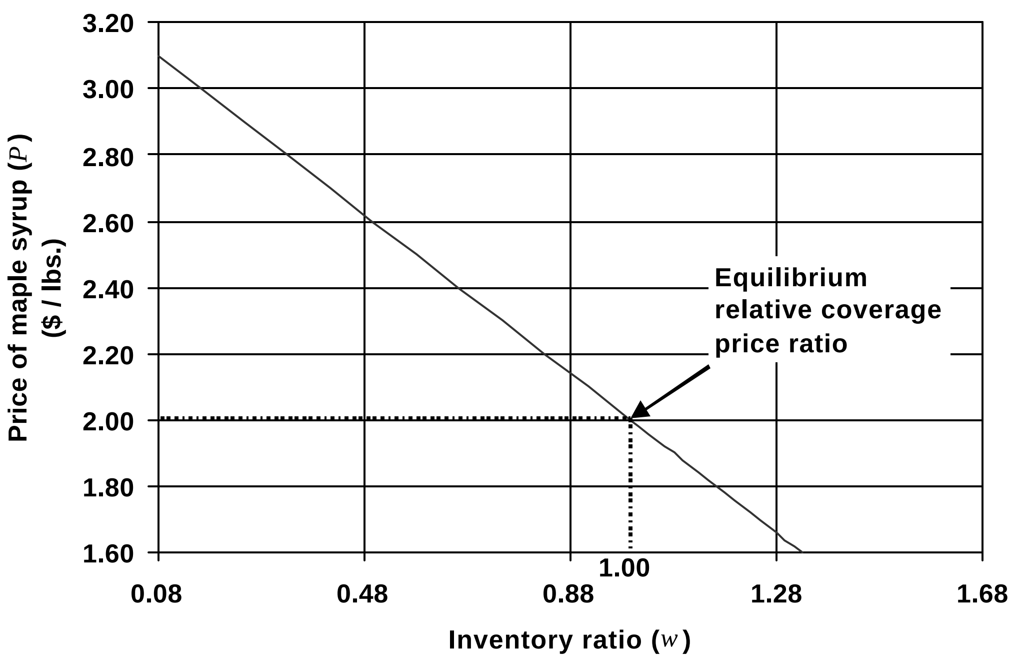


Figure 5 Table function of the inventory ratio and the price of maple syrup

vice versa. Figure 3 shows the function table used to determine the maple syrup price as a function of the inventory ratio as specified within the model.

Second, the supply response, represented by the desired capacity level, was estimated using the univariate econometric equation (9). The dependent variable is the number of taps and the independent variable is the price of maple syrup lagged by one period. These econometric estimates provide the information needed for the calibration purposes of incorporating the supply response in the model.

$$\text{(9)} \qquad \grave{U}_d = 8285.8 + 6528.8\, P_{t-1} \quad ; \quad R^2 = 0.5149.$$

The time series data used for estimating the regression parameters included years from 1974 to 1998 (Statistics Canada ; Bureau de la statistique du Québec). The fitted regression estimates can be seen in figure A1 in Appendix. The measure of goodness of fit is 0.515. This means that 51% of the variance in the econometric model can be explained by the price lagged by one period.

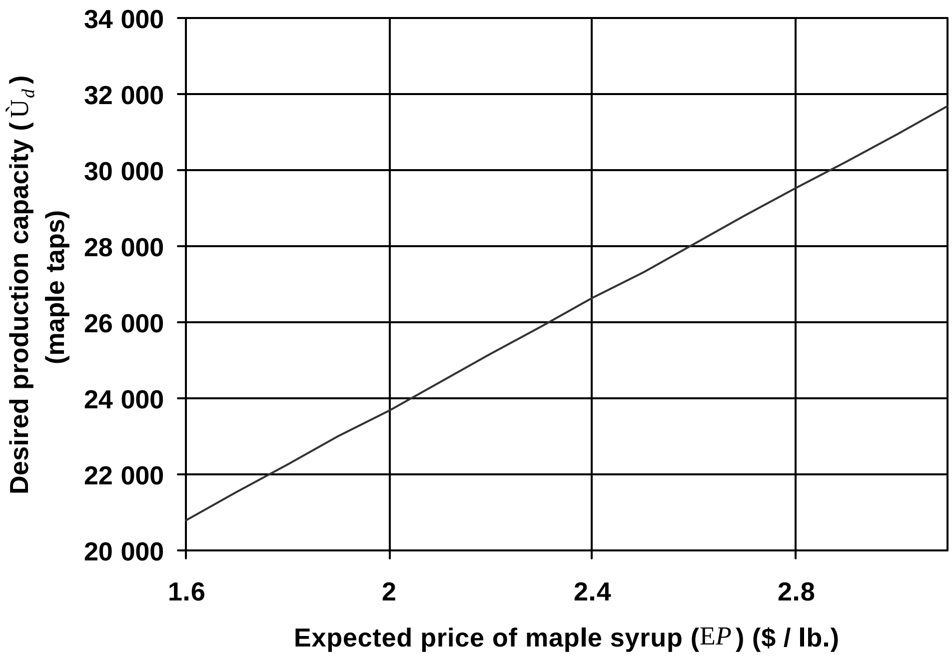


Figure 6 Table function for the supply response

This is quite high given there is only one variable in the model. The supply response in the model, that is, the number of taps as a function of the lagged price expectations, was calibrated using the econometric predicted value for the appropriate price range. The supply response to price expectations is depicted in Figure 6.

The third table function is the demand curve for maple syrup consumption is seen in Figure 7. This also was estimated using a univariate econometric model. The per capita consumption is the dependent variable regressed on the price of maple syrup. The model equation showing estimates is given in (10), and the fitted plot is displayed in Figure A2 in the Appendix,

(10) $$\text{Ë} = 0.3726 - 0.1232\,P \quad ; \quad R^2 = .5166.$$

The goodness of fit measure (R^2) is 0.52. This means that roughly 52% of the variance within the econometric model is explained by the variation in the price of maple syrup alone. Other methods could be employed to estimate the demand as a function of the price of maple syrup. However, the results obtained are adequate within the context of this work.

Simulation Results

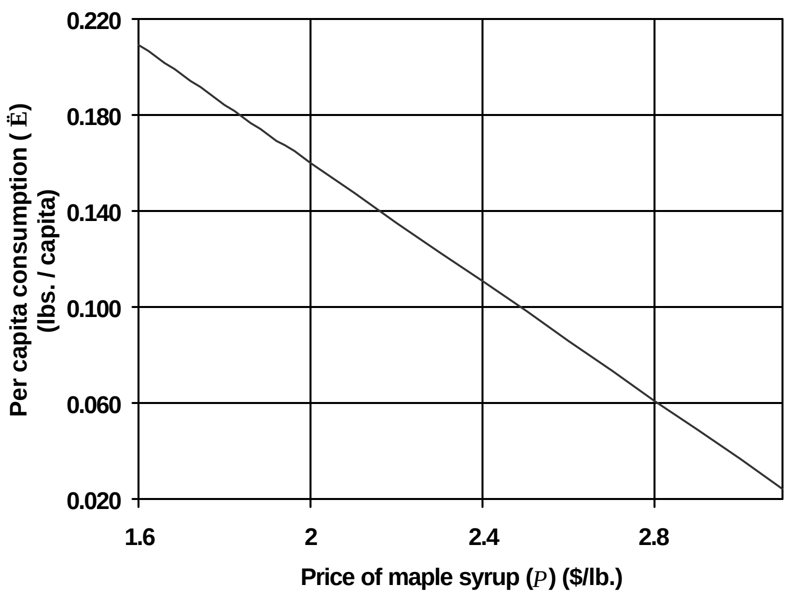


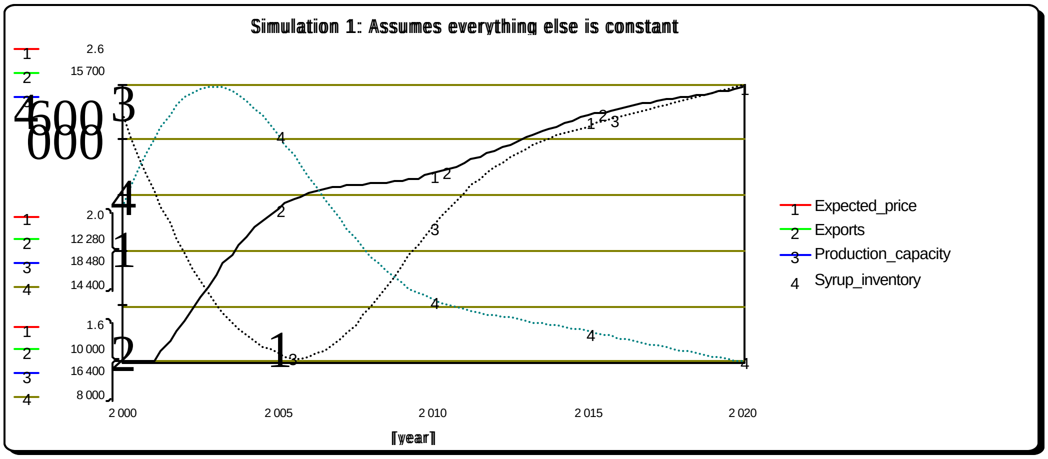
Figure 7 Table function for the demand

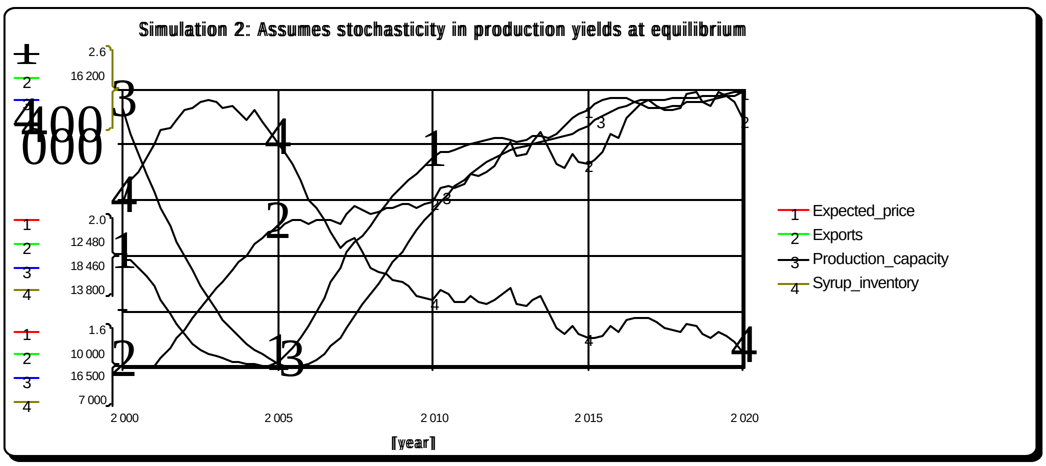
This section presents illustrative simulation results using the baseline SD model. Four questions are asked to the model: What is the impact on the system if the demand for exports grows by 4% per annum for the next 20 years, and:

(1) Everything else remains constant?
(2) The production yield varies according to a Gaussian-normal distributed stochastic variable with a standard deviation 10% around the mean?
(3) The beginning inventory level for maple syrup is below and above the year 2000 level?
(4) The initial productive capacity for maple sap collection is below and above the year 2000 level?

The results are reported on graphs and depict the dynamic adjustment paths of the expected price (line 1), exports (line 2), and the state variables production capacity (line 3) and syrup inventory (line 4).

Simulation 1:





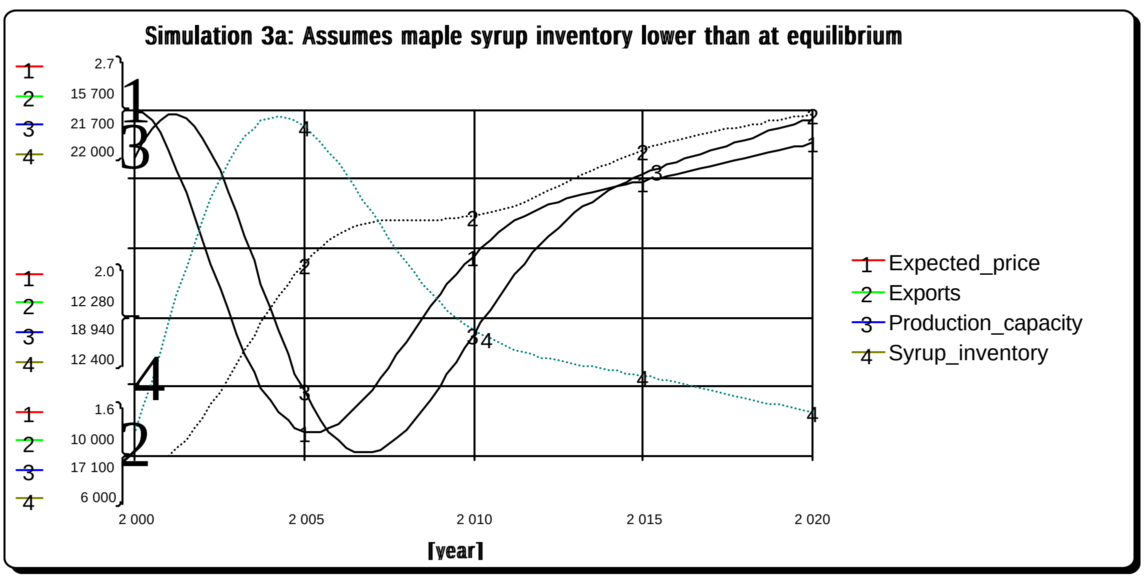
The results of simulation 1 depict the dynamic adjustment path of a 4% growth per annum in exports assuming the state variables production capacity and maple inventory are calibrated to the year 2000 values. As seen, the initial growth in exports would take about two years before the inventory begins to fall. This is because maple inventory surpluses are reflected in the initial conditions of the model and growth in exports are initially too modest to counterbalance the effect of excess capacity and syrup inventory. Because inventory remains high (due in part to existing excess capacity) and continues to accumulate, and because production assets are not removed from production, the expected price keeps falling to the minimum level allowable by the model. Production capacity contracts until it reaches a low in 2005. This process of eliminating the industry excess supply in the form of existing inventory and productive capacity (through the gradual wear and tear of the productive capital) would take until about 2006, or five years following the introduction of the export program. At that point, the expected price would start to rise from $1.60 per pound in 2005, the minimum allowable price by the model to $2.60 per pound in 2020.

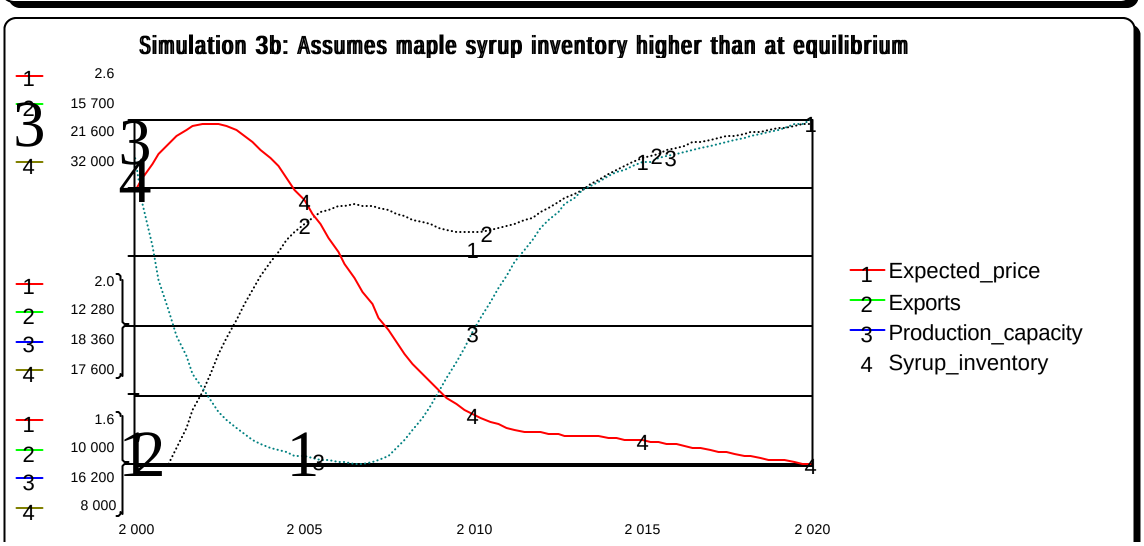
Simulation 2:

The results of simulation 2 exhibit dynamic adjustment paths similar to the ones of simulation 1. The difference between the two sets of simulation results is the introduction of stochastic production yield that follows a Gaussian-normal distribution (N~(0,1)) with a standard deviation of 0.07 pound per maple tap, or approximately 10% around the mean. Note that stochastic production yields do not overwhelm the dynamic behavior created by the structural components of the stock and flow interaction, but rather are useful to introduce some elements of production risk into the model.

Simulation 3a, b:

The results of simulation 3a were obtained by specifying the initial syrup inventory lower than the year 2000 level in the model (6,599 kiloliters instead of 16, 599 kiloliters in the baseline model). This means that at the beginning of the simulation the low inventory puts the expected price at $2.70 per pound. The high expected price remains above equilibrium price until 2002. At this point, producers contract production until 2006, time at which the export program leads to a depletion of the syrup inventory. The depletion of the syrup inventory leads to a rise in the expected price and this sends the incentive to producers to rebuild productive capacity as a





response to the demand for exports. Note that the expected price of maple syrup at the beginning of the simulation is $2.70 per pound, and that by 2020 the expected price remains lower at $2.62 per pound.

For simulation 3b, the initial maple syrup inventory is higher than the year 2000 level (26,599 kiloliters instead of 16,599 kiloliters for the baseline model). This implies that this initial condition of high inventory puts the expected price in the doldrums at $1.60 per pound, the lowest price allowable by the model. Given this initial condition, the production capacity is geared up to keep production flowing and inventory rising until it reaches nearly 32,000 kiloliters in 2002. This is the result of production pressures from not yet depreciated production capacity, which keeps production going at a faster rate than the program for exports. The inventory exercises downward pressure on the expected price that remains at $1.60 per pound until 2007. By 2007, the rise in the demand for exports begins to put an upward pressure on the expected price. As in the previous simulation 3a, the effect of the export program does not begin to exercise pressure on the inventory until 2006. At that point, the syrup inventory and the production capacity are sufficiently depleted to stimulate growth in the supply response.

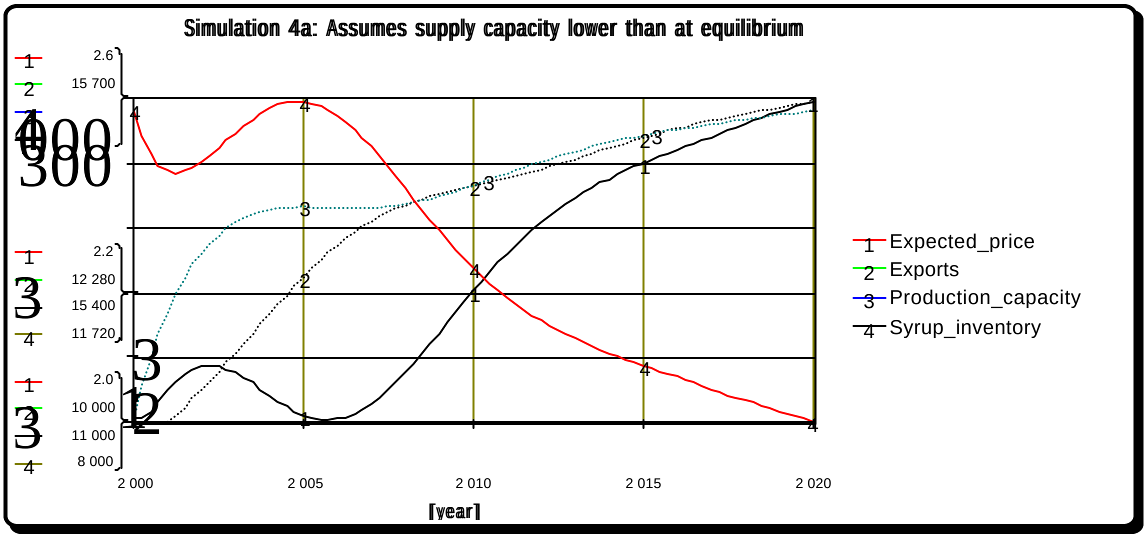
Whether the inventory is over or lower than the year 2000 level, the export program for maple syrup begins to show results after six years of growth. The pain for producers is less, of course, if the expansion driven by the export program begins when the industry has lower accumulated inventory level. Both simulations 3a and 3b reach near identical results by the year 2020. What differ is the adjustment paths of the variables in the system during the first five years of the export program.

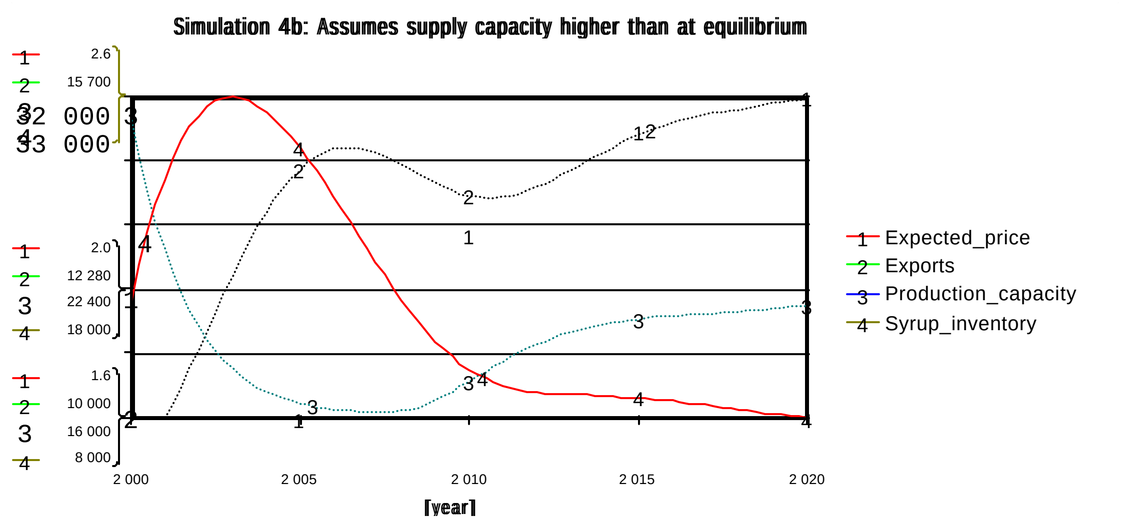
Simulation 4:

The results for simulation 4a were obtained by specifying an initial production capacity lower than the one in the baseline model (11,078 maple taps rather than 21,078 taps). Initially, the lower production capacity has no effect on the expected price. In addition, the production rate is lower and the inventory does not replenishing as rapidly. In this scenario, however, the syrup inventory reaches a new peak at approximately 17,000 kiloliters in 2005, most likely due to capacity expansion overshot that sent the price to $1.75 per pound. By that time, the demand for exports begins to be felt and as the syrup inventory depletes, the expected price begins to rise. Production capacity expands to meet the program's growth objectives.

Simulation 4b considers the case where the initial production capacity is higher than in the baseline model (31,078 maple taps rather than 21,078 maple taps). With the existing excess capacity, the syrup inventory continues to accumulate until 2003 at nearly 33,000 kiloliters. The rising inventory leads to a declining production capacity and expected price. The price begins to rise again by 2008, the point at which the export program provides a sufficient expansion incentive from a declining inventory. This results in a production capacity expansion by 2009.

The results from simulations 4a and 4b show similar outcomes from growth in exports. As for the results of simulation 3a and3b, the outcome is similar for the four dynamic paths studied using the model. Adjustments in production capacity seem to add more delay in meeting the export program objectives than adjustment in the maple syrup inventory.





Summary and Conclusions

The objective of this paper was to report on the development of a SD model that captures the microstructure of maple sap collection and syrup production in Quebec and that can be used to simulate the macrobehavior of the industry. An influence diagram was presented and the microstructure of the stock and low interactions were characterized in a SD model. The model was calibrated using publicly available information and data, and using univariate econometric estimates of supply and of demand functions.

Simulation results were presented to illustrate the macrobehavior of the model. In recent years, the industry has been plagued with inventory surpluses. The development of an export program for the maple sap products industry is a privileged means to eliminate inventory pileups. The results section of the paper presented basic simulation results looking at the time it would take for the industry to receive an incentive to expand capacity following the introduction of the program, assuming various degree of disequilibrium in the maple syrup and production capacity state variables. In most cases it was found that the feedback from the export program takes nearly five years before it can become significant to make a positive difference on price expectations.

The limitations of the model are numerous. The following is an incomplete list of key items that are currently being incorporated in the model:

- It would make sense to disaggregate the supply response according to the size of the production capacity (per farm type) to account for scale economies. Individual farm sizes have a different cost structure and profitability levels. This would allow us to know the intensity of the supply response for each type of production unit. A study has demonstrated that operating costs vary according to size (Bellegarde 2000).

- To help with cash liquidity, the Quebec Government has a program in place that allows producers to borrow the money up to half the price of the maple syrup production. This most likely plays a role in driving up production capacity.

- It would be important to disaggregate the maple syrup inventory. This disaggregation would allow us to track where the syrup is the value chain between production and the consumer.

- The policy an strategic components from large industry participants such as the Fédération des producteurs acéricoles du Québec (FPAQ), and the Regroupement pour la commercialisation des produits de l'Érable du Québec (RCPEQ). These industry participants might have an impact on coordinating supply and demand.

- The underground economy plays a role in the dynamics of the industry.

The model proposed in this paper constitutes an excellent platform towards addressing these limitations and a first step for a greater understanding of the maple sap products industry dynamics.

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Appendix

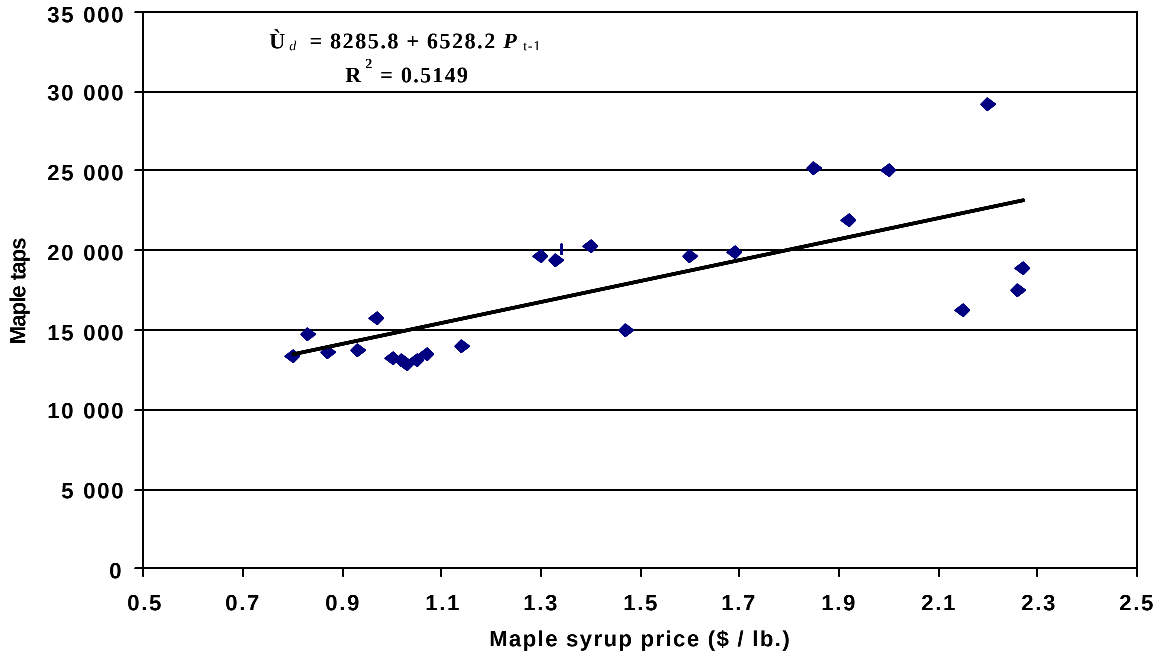

Figure A1 Econometric estimation of the supply response

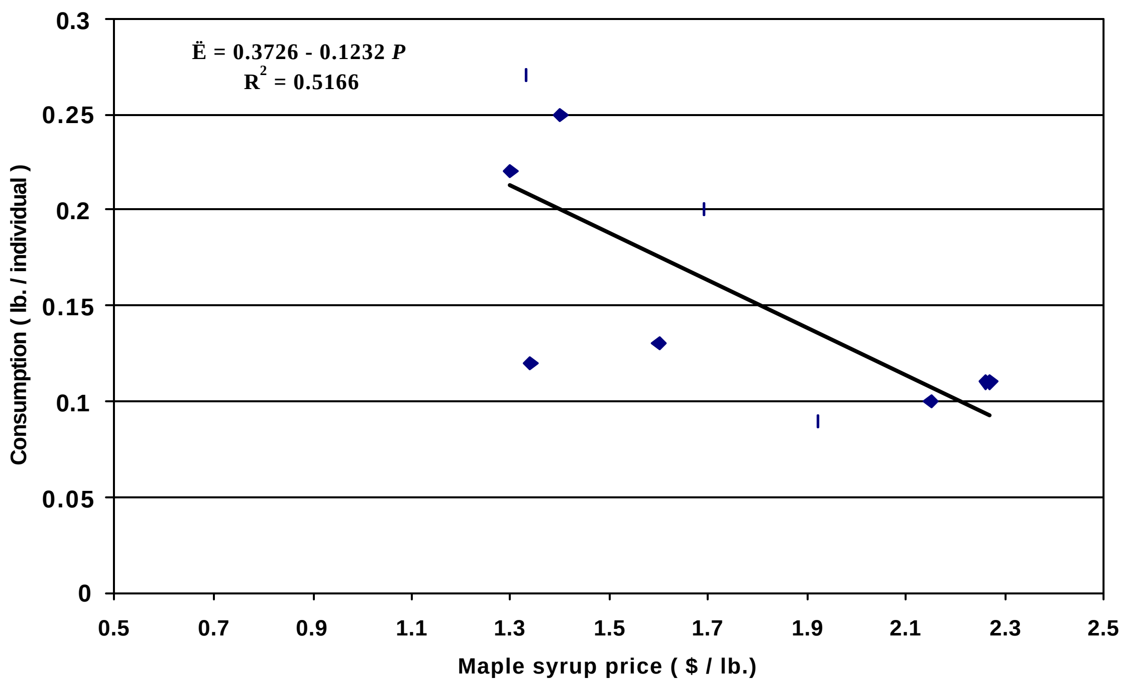

Figure A2 Econometric estimation of consumer demand