The Impact of El Niño on Northeastern Forests: A Case Study on Maple Syrup Production

Nancy Bergeron
Roger Sedjo

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RESOURCES
FOR THE FUTURE
1616 P Street, NW
Washington, DC 20036
Telephone 202-328-5000
Fax 202-939-3460
Internet: `http://www.rff.org`

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Abstract

El Niño events are likely to affect maple syrup production since it is very sensitive to weather patterns. A statistically significant direct correlation has not been found in our preliminary analysis, however. This may be because many other factors affect production and because weather anomalies also occur in non-El Niño years.

Few defensive activities are available to maple syrup producers to alleviate the negative impacts of weather anomalies on their production. Hence, the value of El Niño-Southern Oscillation (ENSO) forecasts to them is likely to be low, even if a clear correlation between productivity and ENSO events was eventually found.

Overall, small welfare impacts of El Niño weather events are expected from their impact on the maple syrup industry, even if a correlation is found. This is mainly because the share of maple syrup production in the economy is very small. Also, only a portion of the exploitable trees is under production and hence some excess capacity exists. Furthermore, maple syrup has numerous substitutes (albeit imperfect) as sources of sugar and luxury food items; the impact on consumer welfare is hence likely to be small.

The most unique feature of maple syrup production includes cultural and amenity values provided by the springtime sugaring off parties; this appears as the least substitutable characteristic of the maple syrup industry. Indeed, few forest-based activities exist at the time of maple sap harvest. In all likelihood, even *if* the development of the industry is slowed down because of ENSO events, this springtime ritual will remain as it does not involve great investment like the larger, more sophisticated activities do. The welfare impact, through the lack of substitute, would be greater if this tradition were to disappear altogether.

Key Words: El Niño, forests, maple syrup, economic welfare effects, dieback

JEL Classification Numbers: D61, Q10, Q20, Q23, N5

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THE IMPACT OF EL NIÑO ON NORTHEASTERN FORESTS: A CASE STUDY ON MAPLE SYRUP PRODUCTION

Nancy Bergeron and Roger Sedjo*

I. ENSO EVENTS

The phenomenon widely known as "El Niño" is a warm weather pattern emanating from the Pacific, usually from October of a given year to September of the next. In the past century, the number of El Niño events has increased in frequency (see Table 1 and Figure 1) as well as in magnitude. The 1972-73 El Niño first called international attention to the phenomenon because it caused the collapse of the anchoveta population exploited for fishmeal production on the coast of Peru. Shortly after the collapse of the fishery, however, interest in El Niño phenomenon decreased and the 1972-73 event was soon forgotten, until ten years later. Indeed, according to recently recorded information and historical accounts, the 1982-83 El Niño was the strongest in more than 400 years; it has been called an "anomalous anomaly" (Glantz 1996), a statistical outlier. Since then, other El Niño events have occurred, one of whose influence lasted much longer, from 1991 to 1995 according to some scientists, and government agencies in different countries have begun to devote research budgets to the phenomenon because of the disruption it often causes. The 1997-98 El Niño event was even stronger than that of 1982-83, and El Niño-related research will undoubtedly continue.

The complete El Niño system is in fact called ENSO: EN- for El Niño and -SO for Southern Oscillation. "El Niño" refers to sea surface temperatures in the Pacific while "Southern Oscillation" refers to pressure at sea level in the Southern Pacific. A warm ENSO event is often called El Niño while a cold ENSO event is in contrast called La Niña or El Viejo. Many definitions exist for El Niño events, but Glantz describes some common recurring aspects of these definitions as follows (pp. 14-15). It is a warming of surface water that appears off the coast of Ecuador, northern Peru and sometimes Chile around Christmas time. It is linked to changes in pressure at sea level across the Pacific Ocean and involves temperature increases in the eastern and central Pacific. It occurs with a decrease in westward-flowing equatorial trade winds and returns around Christmas time. Finally, it generally lasts twelve to eighteen months. Technical definitions are used with specific norms about sea surface temperatures and concurrent differences in pressure at sea level between Darwin in Australia and Tahiti, in order to determine the classification of any ENSO year. Table 1 shows the classification of the 1943-44 to 1996-97 ENSO events according to one source.

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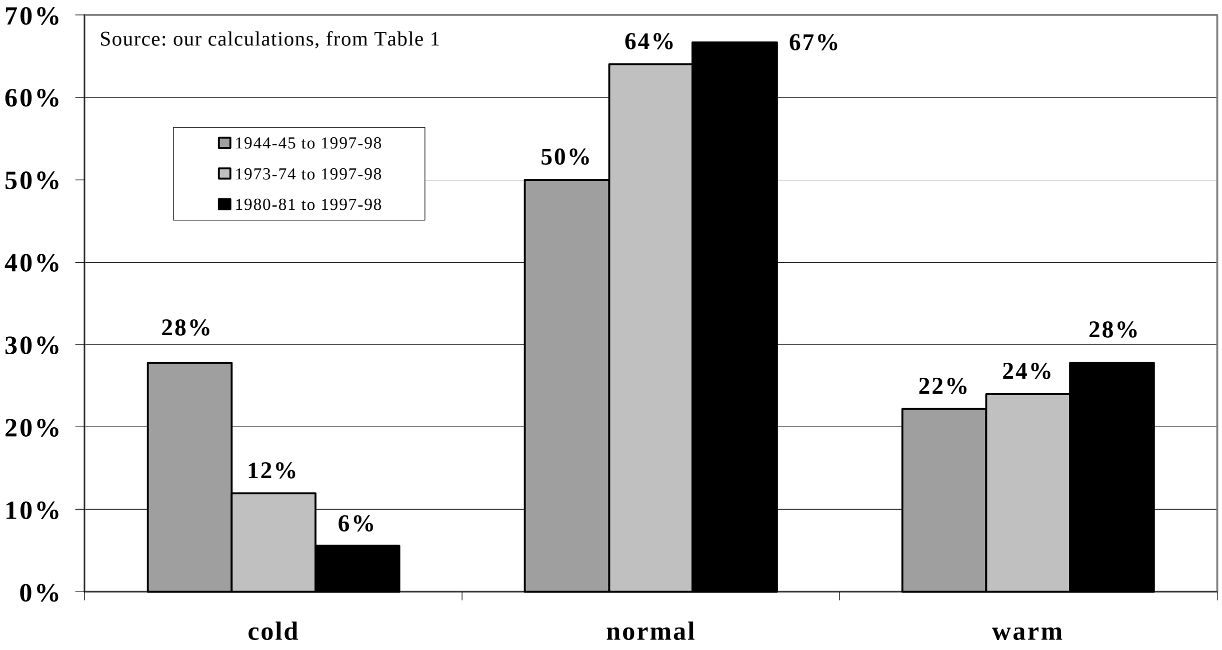
* Nancy Bergeron, Ph.D. Candidate, Agricultural and Resource Economics Department, University of Maryland; Roger Sedjo, Senior Fellow, Energy and Natural Resources Division, Resources for the Future.

Table 1. ENSO events, 1943-44 to 1996-97

Year (Oct.-Sept.)	ENSO Event	Year (Oct.-Sept.)	ENSO Event
1944-45	Normal	**1971-72**	Cold
1945-46	Cold	**1972-73**	**Warm**
1946-47	Cold	**1973-74**	Cold
1947-48	Cold	**1974-75**	Normal
1948-49	Cold	**1975-76**	Cold
1949-50	Cold	**1976-77**	**Warm**
1950-51	Normal	**1977-78**	Normal
1951-52	**Warm**	**1978-79**	Normal
1952-53	Normal	**1979-80**	Normal
1953-54	Normal	**1980-81**	Normal
1954-55	Cold	**1981-82**	Normal
1955-56	Cold	**1982-83**	**Warm**
1956-57	Cold	**1983-84**	Normal
1957-58	**Warm**	**1984-85**	Normal
1958-59	Normal	**1985-86**	Normal
1959-60	Normal	**1986-87**	**Warm**
1960-61	Normal	**1987-88**	**Warm**
1961-62	Normal	**1988-89**	Cold
1962-63	Normal	**1989-90**	Normal
1963-64	**Warm**	**1990-91**	Normal
1964-65	Cold	**1991-92**	**Warm**
1965-66	**Warm**	**1992-93**	Normal
1966-67	Normal	**1993-94**	Normal
1967-68	Cold	**1994-95**	Normal
1968-69	Normal	**1995-96**	Normal
1969-70	**Warm**	**1996-97**	Normal
1970-71	Cold	**1997-98**	**Warm**

Source: Green, Legler, Miranda, and O'Brien (1997).

Figure 1. Frequency of ENSO Events over Different Time Intervals



In Spanish, El Niño literally means "The Little Boy." This name has been used for generations in reference to Jesus because of the warmer water currents that move southward along the coast of predominantly Catholic Peru around Christmas time. The appearance of unusually warm currents has disrupted coastal ecosystems and socioeconomic activities for centuries along the West Coast of South America. There is evidence that El Niño events have occurred for millennia, but only recently have scientists begun to realize the potential effect it has on global weather. Indeed, scientists now believe that ENSO events have significant impacts on global weather through what they call "teleconnections" between geographically distant weather patterns. Recent evidence of weather anomalies all over the world in "El Niño years" tends to support these assertions.

The reason why El Niño events occur more frequently and in greater magnitude than before remains unclear, however. It is not known if it is a definite trend, or if it is the simple manifestation of stochastic weather events, which can be anomalous at times without any underlying long-run trend. Some speculation exists on the potential links between El Niño events and global warming. If the phenomena are linked as speculated, then, as the global climate warms up, we could expect the frequency and magnitude of El Niño events to increase. The overall social costs of such a potential link are likely to be important.

For example, El Niño is the suspected cause of catastrophic weather in the winter of 1998 in northeastern North America. The 1997-98 El Niño event was the highest in magnitude ever recorded, and unusual weather patterns were expected for the year to come all around the world. In northeastern North America, spectacular ice storms occurred in New England, New York and eastern Canada in January 1998. Southern Québec was particularly affected with extensive blackouts that lasted up to three weeks in some regions. The blackouts and unusually iced roads contributed to many losses in production and losses in capital such as dead animals in agricultural areas, cars damaged by ice falling from trees, damaged houses and power lines, and numerous delays in delivery of inputs to industries and final goods to markets. The total estimated damage in Québec and eastern Ontario was about $1.5 billion, a quarter of it being damage to the hydro-electric network (Schneider 1998).

In this case study, our interest lies in the effects of ENSO on the maple syrup industry and on defensive/preventive actions if a specific ENSO event is expected. The 1998 ice storms were costly in at least three ways for the maple sugar industry. Firstly, the harvest infrastructure was damaged by broken branches due to heavy ice and snow in several places, requiring pipeline collection systems to be fixed or replaced. Secondly, production costs were increased because access to sugarbushes was made difficult due to fallen branches. Finally, maple crowns were moderately to severely damaged, some younger trees being altogether uprooted or decrowned. Damage was most severe in southern Québec and northern New York State, but was also present in eastern Ontario, Maine, New Hampshire and Vermont (Irland 1998). Estimates of taps lost to the 1998 ice storm are given in Table 2. Québec producers, who have a centralized stock management system, had little syrup in inventory from 1997 and expected the price to increase after the storm. It indeed increased from 1.85$CDN/lb in 1997 to 2.20 in 1998, the highest price since 1988 (FPAQ 1998, preliminary estimates). In Vermont, the storm was severe enough to damage trees and the maple syrup production was expected to decrease by 10 percent, while prices were expected to increase by about 10 percent (Browne 1998). It is believed that it will take about five years to get back to the same level of tapping as before the ice storm (Irland 1998).

Table 2. Maple Taps Lost to the 1998 Ice Storm

	Taps lost	Percent of taps lost in each region
Maine	15,000	2.0%
New Hampshire	59,000	12.5
New York	400,000	20.0
Vermont	57,000	2.0
US total	***531,000***	***6.5***
Ontario	150,000	12.5
Québec	2,600,000	10.0
Canada total	***2,750,000***	***9.7***
World total	***3,281,000***	**9.2**

Sources: Irland (1998), Kerry et al. (1998).

Clearly, *if* weather anomalies such as those described above are caused by El Niño events and *if* they increase in frequency and in magnitude over time, damages could be important and the overall cost of improving existing infrastructure to avoid damages could be large. However, there is great uncertainty regarding the trend of anomalous ENSO events, the impact of these events on world weather patterns and even on the effect of weather patterns on local occurrences, such as maple syrup harvest levels and quality. The purpose of ongoing El Niño-related research is to decrease the uncertainty and to facilitate policy-making that could curtail the social costs related to ENSO anomalies.

There exist different types of research efforts linked to El Niño. Research on the social benefits due to better ENSO forecasts helps enlighten the benefit-cost considerations of further ENSO-related research. For example, previous studies estimate such benefits to agriculture (Adams et al. 1995; McNew 1997) and to fish population management (Costello et al. 1997). In a general equilibrium framework, Adams et al. estimated the value of improved ENSO forecasts to be about $100 million (1990) for the agricultural sector in the Southeastern United States. McNew's point is that corn storage can serve as a buffer against future potential harvest shortfalls and that in the long run, if weather forecasts were improved, then storage, and its associated cost, would decrease because of the decreased uncertainty. He estimates the benefit (through changes in commodity storage only) of a perfect ENSO forecast to be $240 million (1997) for the US corn market alone. He also finds that improving an already good forecast is more valuable than improving a forecast with less accuracy, which is evidence of increasing marginal returns to forecast accuracy. Costello et al. have found that it is more beneficial to have more precise El Niño information on a one-year time frame rather than to keep the same level of precision but to obtain the predictions longer in advance. This result obtains because of the short lapse of time to adjust the catch to the expected fish growth given an ENSO event.

Studies such as these can serve as a basis to orient future El Niño research. Better predictions also permit the elaboration of better defensive activities when floods, droughts or storms are expected in a given region. Meteorological research can also help better understand teleconnections and the potential link between recent anomalous El Niño events and global warming. Until the link, if any, between ENSO events and global warming is understood however, we cannot be sure that recent events represent any specific trend.

II. MAPLE SYRUP PRODUCTION

Secrets to Maple Syrup Production: maple physiology and weather

Maple sap has been tapped from maple trees since before the arrival of Europeans in North America. The most ancient writing that mentions maple sap is from Father Paul Lejeune and dates back to 1634 (Campeau 1995). At the time, the springtime ritual was widespread in the region that was to become New France, while it appeared later in what is now New England. After the long winter, the faintly sweet liquid provided much needed carbohydrates to indigenous populations. Later, the French, who knew how to produce sugar from sugarcane in their Haitian colony, are believed to be the ones who first attempted concentrating maple sap into syrup and sugar by heating it (Campeau 1995). With this transformation, sugar conservation was made easier for consumption through the whole year and "Indian sugar" (*sic*) could also be exported to France.

Maple sap gathering is a type of non-timber harvest from forestry. It draws sap from the trees for maple syrup production without endangering the trees, when done cautiously. It is only practiced in northeastern North America and only three sub-species of maple permit such production. In decreasing order of suitability for maple syrup production, the sub-species are *Acer Saccharum* Marsh. (sugar maple), *Acer Rubrum* L. (red maple) and *Acer Saccharinum* L. (silver maple) (Jolicoeur 1995). Maple sap can only be extracted in a limited geographic and seasonal range because of the climate requirements, and sap can only be gathered from the sub-species mentioned because of their unusual physiology.

The physiological process that allows for maple sap gathering is not completely understood yet, but there are some known physical and chemical processes linked to the phenomenon (Bertrand 1995). Absorption of sugar from the roots into the tree occurs during cold springtime nights. The branch extremities freeze as well as the sap inside of them. This then attracts the unfrozen sap from the trunk onto the extremities of the branches. Even though water volume expands when it freezes, maple wood properties provide the explanation for the absorption process just described. Wood fibers are composed of dead cells. In sugar maple, unlike in other species, the dead cells are filled with gas rather than water. These gases, unlike water, *contract* as temperature decreases. This creates space for the water to expand as it freezes, and there is enough space left for more sap to be sucked up by capillary forces from the roots to the branches through the tree xylem. In vascular plants, the xylem consists of outer wood vessels that bring water and nutrients from the roots to the leaves. This absorption process also occurs with transpiration through the leaves' stomata during the summer. In the early spring, however, the frozen sap is captive in the branches during the night until it thaws during the day. Without leaves, transpiration cannot occur and some of the sap must go back down as the temperature rises. This process is called exudation.

Exudation occurs during warm spring days after cold nights. As branches warm up, the gas from wood fibers expands again, the sap thaws and, by gravity, flows back down through the phloem (inner bark) where it can partially be tapped. More sap can be harvested when freezing occurs slowly since more water is sucked up to the branches before it all freezes in the xylem. The gas-filled wood fibers in maple, which permit absorption and then exudation, explain only part of the sap gathering phenomenon since an abundant harvest is furthermore correlated with a high level of sucrose in the sap.

When temperatures approach the freezing point in the fall, the starch accumulated during the summer in the roots of the trees are transformed into sucrose. Sucrose is a necessary component for sap to be abundant enough for a good harvest to occur. On average, the sap is composed of 3 percent sugars, 95 percent of which is sucrose. The precise role of sucrose in conjunction with the physical process described above is not well understood, however.

Maple sap is collected during about one month each year under very specific weather conditions that are usually encountered in Northeastern North America in the springtime.

These conditions are a combination of cold nights, slightly below the freezing point (less than 25°F), and contrasting warm sunny days (greater than 40°F), with a sufficient amount of snow on the ground to provide insulation of tree roots. Also, the longer the ground remains frozen, the longer budding is delayed and the longer the "sugar season" lasts. Hence, long bitter winters generally make for a better sugar season than warm ones. Budding rapidly brings about an unpleasant "buddy" flavor to the sap, signaling the end of the harvest season. Warmed roots also promote the development of micro-organisms that rapidly make the sap non-comestible. Details in the weather pattern matter as the weather influences the harvest in complex ways. For example, a cloudy but otherwise perfect sugar season will produce less sap than a sunny season would because the bark will not warm up as much as if the sun was beating on it.

The weather in the preceding summer also matters a great deal. A warm and sunny summer will allow more starch to be produced and stored in the tree roots than otherwise. It is the mechanism through which the tree stores nutrients in preparation for the winter followed by the high energy needs of burgeoning in the spring. Less sugar stored in the tree roots means less sugar in the sap, and even though an abundant sap harvest might still be obtained, it would likely be of lesser quality and produce less syrup in the end. Indeed, more sap would be needed to produce a given amount of maple syrup with the optimal 66.5 percent sugar density. The weather in the fall preceding a given harvest season also matters since the soil must freeze before snow covers the ground for the season. If it snows before the soil freezes, and the snow accumulates until the next spring without the soil freezing, then the bacteria level will be high in the sap as soon as the sugar season begins and so the sap will likely be of mediocre quality.

Through general tree health, the quantity and quality of the sap harvested is also a function of the weather, months and even years before a given harvest. Bad weather, relative to ideal conditions for sap gathering, can not only affect a given year's sugar season, but also have repercussions for years to come if the trees are damaged. Weather patterns also influence disease and parasite epidemics in intricate ways. Diseases and parasites that weaken the tree in any way will in turn also affect the harvest. If the tree's nutritional reserves are already low due to disease, parasites or healing wounds due to past extreme weather events, collecting the sap can be detrimental and increase tree vulnerability. Skipping a harvest is sometimes advised in order to let a tree recuperate. In an otherwise healthy tree, however, harvesting does not affect the health of the tree. Sap harvest can thus be influenced by the weather directly or indirectly, in ways that can be difficult to track down.

Sap Gathering and Transformation Techniques

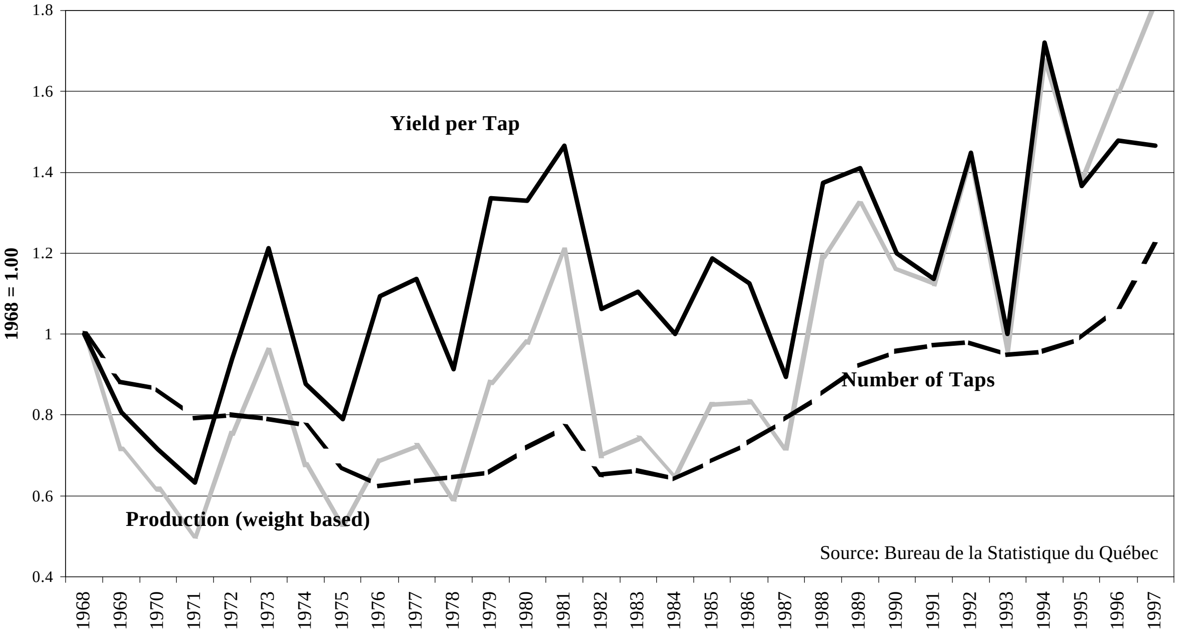
Maple syrup and its by-products are made by heating maple sap so that water evaporates from it. The temperature and duration of this transformation process is key to the final product obtained, given the sap used. However, the raw sap quality is the single most important constraint on the quality of the final product.

Sap harvest starts when the tree is about 30 years old or about 12 inches in diameter. A maple tree can grow as old as 400 years and measure 90 to 120 feet high as an adult. A healthy tree can be tapped every year for decades, even a century, if it is done properly. Recommendations for sound tapping are as follows. New holes should not be bored closer than 2 inches horizontally or 16 inches vertically from a former hole which is still healing (former tap less than 3 year old in healthy trees, longer in vulnerable trees). If new holes intersect with recent and still healing holes, it is likely to trigger the spread of microorganisms and diseases. Tap holes are drilled with a slight upward slant and should be no more than 0.5 inch in diameter and 1.5 to 2 inches deep. Holes must be pierced into a tree each year, in increasing number with tree age. Maples with DBH (diameter breast height, i.e. at about 4.5 feet from the ground) less than 8 inches should not be tapped at all. It is then recommended to bore one taphole per additional 8 inches of DBH diameter, with a maximum of three tapholes per tree (Boily 1997). More holes would not permit collection of more sap and would cause more harm than optimal to the tree, making it harder than necessary for it to heal. Taps must be removed as soon as the sugar season ends to facilitate the healing process.

In the past, paraformaldehyde (PFA) pellets were inserted into tap holes to prevent damage to the trees and to delay the spread of microorganisms into the hole, and thus promote a more abundant sap flow. PFA residues evaporate in the transformation process and so are believed not to present any human health hazard. There is some indication however that continuous use of PFA can cause tree damage through cambium death around tapholes, which hinders taphole closure and nutrient transport in the long run. For this reason, this practice has recently been banned. Without PFA, careful tap hole management has become particularly important for tree health. Ethylic alcohol (70 percent) is now suggested as a substitute for it in order to prevent the development of micro-organisms (FPAQ 1997). It is applied when tapholes are bored into the trees and evaporates rapidly without causing taphole scarring the way PFA did.

Different materials have been used in the past for tapping, but nowadays, aluminum or plastic spiles are the rule. In smaller, more folkloric production, the sap flows down into a bucket placed under each tap hole and is collected each day. Large operations use plastic spiles and tubing that collect the sap from many trees into larger mainlines and finally into large tanks that are emptied each day as well. Maple sap must be processed rapidly since fermentation takes little time to occur. Collection through plastic tubing is more efficient and has the advantage of limiting the passage of heavy machinery in the forest, which can compact the soil and damage tree roots. For sap flow, closed tubing systems can use the natural vacuum created by gravity on a terrain slope, or artificial vacuum. Without a natural slope or artificial vacuum, the systems are vented, that is they let air in at the tap hole in order to prevent vapor locks which would slow the sap flow to the collecting tank. There is some doubt about whether or not artificial vacuum can damage trees; if used, it should not extract much more sap than under a natural vacuum, that is, about 10 percent of the sap in a tree (Cedarvale Maple Syrup Company 1998). Output is generally greater under artificial vacuum, mostly because the spread of microorganisms is limited with such a system and because sap gathering can start earlier and end later each day. Tapholes last longer under a vacuum pumped system. This technique has become more widespread in larger operations, and data from Québec, where operations have substantially increased in size over time, indicate a consistently increasing trend in average output per taphole (Figure 2).

Figure 2. Maple Syrup Production, Number of Taps and Average Yield per Tap in Québec, 1968-97



Source: Bureau de la Statistique du Québec

In the province of Québec for example, the average output is about 2 lbs. of maple syrup per tap per year. Over the past 30 years, the minimum seasonal average has been 1.02 lb./tap in 1971 and the maximum has been 2.77 lbs./tap in 1994 (FPAQ 1997). There is an upward trend in the output per tap, due to improved techniques and perhaps to some tree selection, but it still varies substantially from one year to another. In the past ten years, the minimum has been 1.61 lbs./tap, in 1993.

One gallon of maple syrup weighs 11 lbs., which means that it takes on average about three tapped trees to produce one gallon of maple syrup per sugar season. The sap contains 2 to 3 percent sugar while the syrup is concentrated to 66.5 percent. Hence, depending on the quality of the sap in any given year and on the time within the sugar season during which some variability can be observed, it takes 30 to 45 gallons of sap to produce one gallon of maple syrup (Cedarvale Maple Syrup Company 1998). The chemical composition of maple syrup is about 66 percent carbohydrates, mostly sucrose, with small amounts of organic acids, amino acids, minerals, and vitamins.

The sap is collected and then brought to the sugar house for transformation. It can be treated with ultra-violet light to delay fermentation and is always filtered for debris. The fresh sap is then boiled in flat metal tanks called "evaporators" the same day it is gathered. No additives are used, except for small quantities of fat, such as butter, or alternatively a synthetic product, both of which prevent foaming as the sap is heated. The fat and other residues are removed by filtering the syrup before bottling or canning it. In larger operations, reverse osmosis removes part of the water from the sap by ultra-filtration rather than heat, at lower energy cost, *before* boiling and condensing it further. Some producers believe that this process results in differently tasting syrup, however, and choose to continue using the evaporator alone.

Maple syrup is bottled or canned and can be stored for many years before it is eaten. Maple taffy, served on the snow at "sugaring off" parties, maple spread, maple sugar and maple candy are made by concentrating the liquid even further. All these products can be purchased or made at home from maple syrup. Technological change was slow in the maple syrup industry, probably because production has remained a folkloric family affair, as a simple springtime hobby, for a long time. Nowadays however, some producers are avid business people and the industry is growing and becoming more organized, especially in Québec. Some of these specialized exploitations, with up to hundreds of thousands tapholes per year, do not offer sugaring off parties on the farm anymore and sell their entire syrup stocks in bulk on different markets.

As the population became more sedentary and later more health conscious, *per capita* consumption of maple syrup decreased over time in the traditional consumption areas, which were generally close to the production areas. Continued efforts are now made to promote maple food products as luxury products, to create new, sophisticated maple food products and to promote them on the international scene. Research programs exist to transform syrup and introduce it in new products such as ice cream, yogurt, pastries, *etc*. Chemistry research is carried out to precisely define what maple syrup is, so that imitators and adulterators of maple syrup can be prosecuted. Storage management has also become an important part of the more organized maple syrup industry in the province of Québec, where producers are market leaders with more than 70 percent of current world production. There, not only do producers hold stocks as they always have, but there exists something akin to a maple syrup board (called Regroupement pour la commercialisation des produits de l'érable du Québec) that buys and sells bulk syrup, depending on the market condition every year. The industry has been in constant evolution for the past 15 years or so in Québec and different institutions have come and gone, but the trend towards market organization and expansion remains, and current marketing institutions are improving over past ones.

In the U.S., some exploitations market their products worldwide, but usually at a relatively small scale. There also exist Maple Promotion Boards, such as in Vermont, but in general production and marketing remain more traditionally oriented. It used to be that maple sugar-related research was more prominent in the United States, but nowadays the situation is reversed. Maple syrup exploitation and production data are also gathered more consistently and are easier to obtain in Canada. Somewhat surprisingly, research on maple tree genetics and maple syrup is also done in Europe, in the hope of producing syrup there some day; experimental plantations also exist in New Zealand (Cedarvale Maple Syrup Company 1998).

Products and Markets

There are about 16,000 producers of maple syrup in the world. The northeastern United States produce about 20 percent of world output with 5000 operations. Eastern Canada produces the rest, with a high concentration in the province of Québec where 9,000 operations (excluding very small operations) produce more than 70 percent of the world output (Figures 3 and 4).

Maple syrup production varies considerably from year to year, mainly because of its strong and convoluted dependence on weather patterns, as was explained above. Over the past fifteen years, however, a clear trend has emerged as world production nearly doubled (Table 3). There has been no clear trend in the US production however. It has fluctuated up and down but the 1997 production level was about the same as in 1984. A clear trend is present however in the US *percentage* of world production: it produced 38.2 percent of the world maple syrup output in 1984, but it is down to about 20 percent in the late 1990s. The bulk, i.e. 95 percent, of the world increase in maple syrup production has come from the province of Québec. Production in Québec has indeed more than doubled between 1984 and 1997, and its share of the world production has gone roughly from 55 percent to more than 70 percent. Production from other Canadian provinces has almost doubled but its contribution to world production has remained below 10 percent, except for the relatively productive 1992-93 seasons.

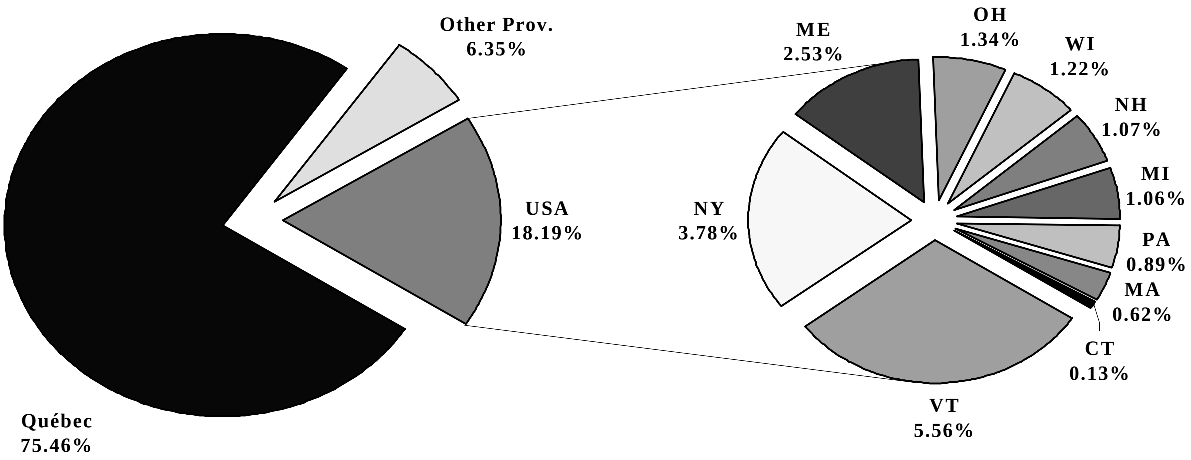
Table 3. World Production of Maple Syrup, 1984-97

Year	USA ('000 lbs)	USA % of World Total	Québec ('000 lbs)	Québec % of World Total	Other Canadian Provinces ('000 lbs)	Other Canadian Provinces % of World Total	World Total ('000 lbs)
1984	14880	**38**	21237	**54**	2861	**7**	38978
1985	14510	**32**	26864	**60**	3308	**7**	44682
1986	11289	**28**	27083	**67**	2347	**6**	40719
1987	9991	**28**	23360	**66**	2013	**6**	35364
1988	13278	**24**	38760	**71**	2870	**5**	54908
1989	13659	**23**	42988	**72**	2734	**5**	59381
1990	12667	**24**	37828	**71**	2994	**6**	53489
1991	14525	**27**	36552	**67**	3225	**6**	54302
1992	18100	**25**	46667	**64**	8188	**11**	72955
1993	11107	**23**	31235	**66**	5158	**11**	47500
1994	14603	**19**	54557	**73**	6000	**8**	75160
1995	12088	**19**	45000	**72**	5000	**8**	62088
1996	17200	**23**	52040	**69**	6000	**8**	75240
1997	14262	**18**	59000	**75**	4963	**6**	78225

Sources: USDA; Bureau de la Statistique du Québec

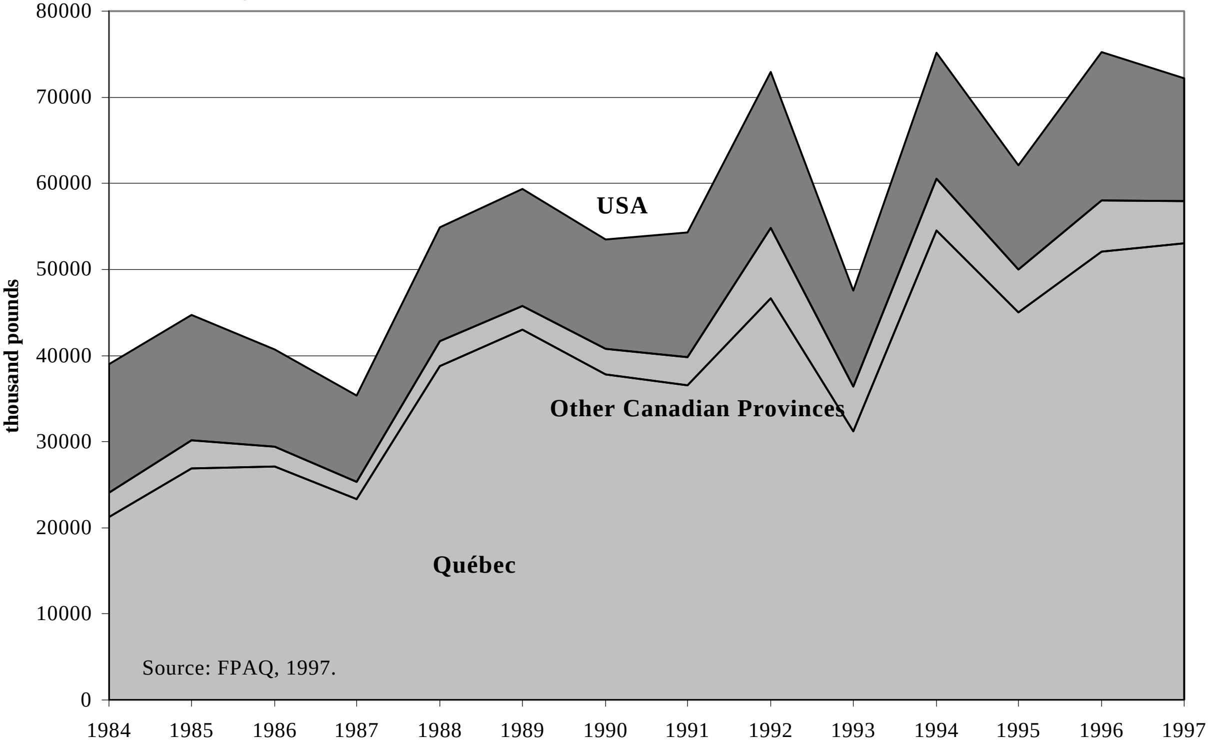
Figure 3. Maple Syrup World Production, 1997

(% volume)



Source: FPAQ, 1997.

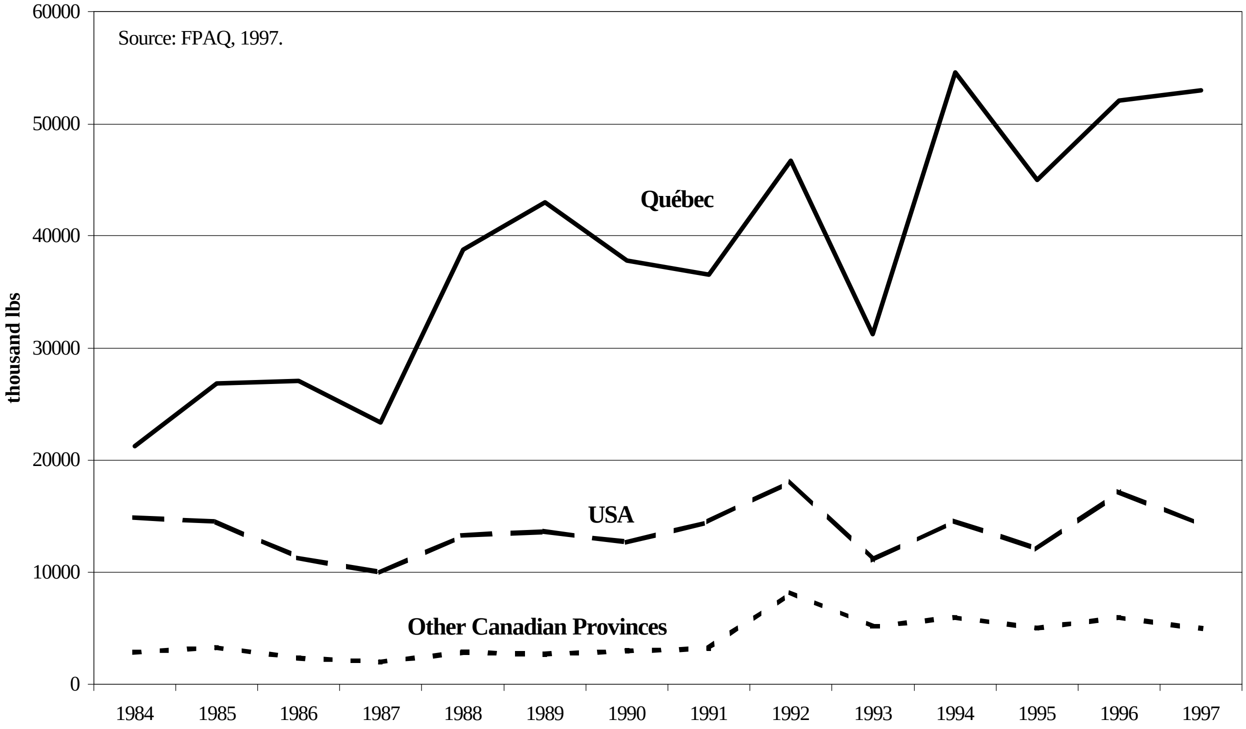
Figure 4. Cumulative World Maple Syrup Production, 1984-97



Source: FPAQ, 1997.

Abstracting from trend in production, fluctuations are often positively correlated in Canada and in the US (Figure 5). This suggests that forces underlying the annual variability are similar for all regions. These fluctuations are due to market forces of course, where supply responds to fluctuating demand, but they are also, in part, natural stochastic fluctuations due to weather patterns and parasite epidemics affecting harvest levels and quality. Since the geographic range of production is more limited on the East-West axis than on the North-South axis, and since weather patterns move East to West, we can expect the maple syrup production geographic range to be affected in a somewhat similar fashion by weather. However, considering North-South temperature differentials that lead to harvest seasons being a month apart in Vermont *versus* Québec for example, weather patterns will not have the exact same effect on production everywhere. A relatively warm winter is likely to affect production adversely everywhere, but the specific weather during harvest season, for example, could be drastically different so that the overall warm weather effect would result in different magnitudes of harvest fluctuations.

Figure 5. World Production by Region, 1984-97



Source: FPAQ, 1997.

III. CROWN DEATH, MAPLE DIEBACK AND DECLINE

Substantial dieback was observed in maple forests in the past century, but in the 1980s it seemed more severe than before. Not only were sugar maples affected, but red maples and a number of maple-associated species were too, making this dieback episode a maple forest (or ecosystem) dieback. Recent dieback episodes were accompanied by what has been termed tree crown death. Crown death is the death of some or many branches, usually at the top of the tree, while dieback is a generalized decrease in tree vigor. Transparency, an inverse measure of leaf density, is used as an indicator of dieback in a tree. Tree decline is a further decrease in vigor that often leads to death of the tree.

The recent dieback and crown deaths are worrisome for maple sugar producers and forest managers, however, since they are present over a wide geographic range as well as across more species than before (Gagnon and Roy 1995). Research programs have been initiated in order to find out the cause of such dieback. In the early 1990s, scientists concluded that there is not one cause, but rather a number of potential correlated causes.

A number of diseases due to different stresses cause crown death and dieback. Stresses that *trigger* maple dieback are those that most impede photosynthesis, the storage of nutrients for the winter, and the absorption and transport of nutrients in the tree. Such stresses are defoliating insects, mushrooms, drought, flooding and weather anomalies. These stresses in different combination can have dire consequences and it is generally difficult to determine which stress caused what precise effect. For example, 60 percent insect defoliation or more will cause a second burgeoning that will use a great amount of starch and sugar reserves in the tree in order to produce a new generation of leaves. This will make the tree more vulnerable and a subsequent snow-less winter would likely cause severe dieback. Such events would decrease the quantity and quality of sugars available for sap harvest, and the harvest could itself endanger the tree further. Low species variability and open landscapes such as those around a recent forest thinning make trees more vulnerable to defoliating insects, which often start dieback episodes.

Acid rains were long suspected as a major cause of maple dieback. Some scientists believe that acid rains, ozone and heavy metals pollution can modify the forest nutrition cycle, but the mechanism through which such modification would occur has not been determined. Scientists are therefore not unanimous about the potential link between atmospheric pollutants and forest dieback (Gagnon and Roy 1995).

The North American Sugar Maple Project (NAMP), a joint project of the Canadian Forest Service, Natural Resources Canada and the USDA Forest Service, was initiated in the late 1980s to monitor the rate of change in the crown conditions of sugar maples (Lachance et al. 1995). Under the NAMP, a number of sample plots were monitored in Canada from 1988 to 1993, a period in which the health of maple forests improved, especially in Québec, where the dieback had been more severe. In the sample studied, crown conditions presented small differences between stands managed for sap harvest and non-sugar bushes. These differences are probably due to soil compaction, tree wounding, frequent light thinning and tapping in sugar bushes, which are likely to make trees more vulnerable to stress. Crown condition did not vary with levels of acidic deposition, but there was a slight increase in transparency with increased deposition of nitrates, indicating slight dieback. The potential negative effect of acid rain on maple forests was not eliminated in this study, but it was not confirmed beyond a doubt either since a slight correlation does not confirm causation. Dieback and transparency levels increased with tree diameter, corroborating the generally accepted notion that older trees are more vulnerable to stress than younger ones. Tree mortality was greater for larger trees, but no difference in mortality was revealed between sugar bush and non-sugar bush stands. Not surprisingly, the initial level of dieback was positively correlated with further decline, and the rate of taphole closure in sugar bush stands was decreased for trees affected by dieback. The study concluded that stresses such as drought, insect defoliation and adverse soil properties had a greater impact on crown condition than acid precipitation and sugar bush exploitation. Furthermore, experimentation suggested that acute stress, such as root freezing due to a lack of snow on the ground in the winter, is more likely to trigger decline than light chronic stress such as levels of pollution.

Gagnon and Roy offer a classification of tree stresses based on Manion's work (Manion 1981, p.14). They suggest three general kinds of tree stresses: (i) stresses predisposing dieback; (ii) stresses triggering dieback; and (iii) stresses aggravating it. We summarize in Table 4.

Table 4. Classification of Tree Health Stresses

Stress	**Predisposing dieback (permanent stress – long run, low grade)**	**Triggering dieback (short run stress, high intensity)**	**Aggravating dieback (stress more likely to occur when tree is already vulnerable)**
Habitat characteristics (soil moisture, soil nutrients)	✓		
Forest management and exploitation	✓		
Genetics	✓		
Global climate change	✓		
Air pollution	✓		
Insect defoliation		✓	
Climate anomalies (frost, drought)		✓	
Local sources of pollution		✓	
Mechanical injury		✓	
Parasites			✓
Viruses			✓

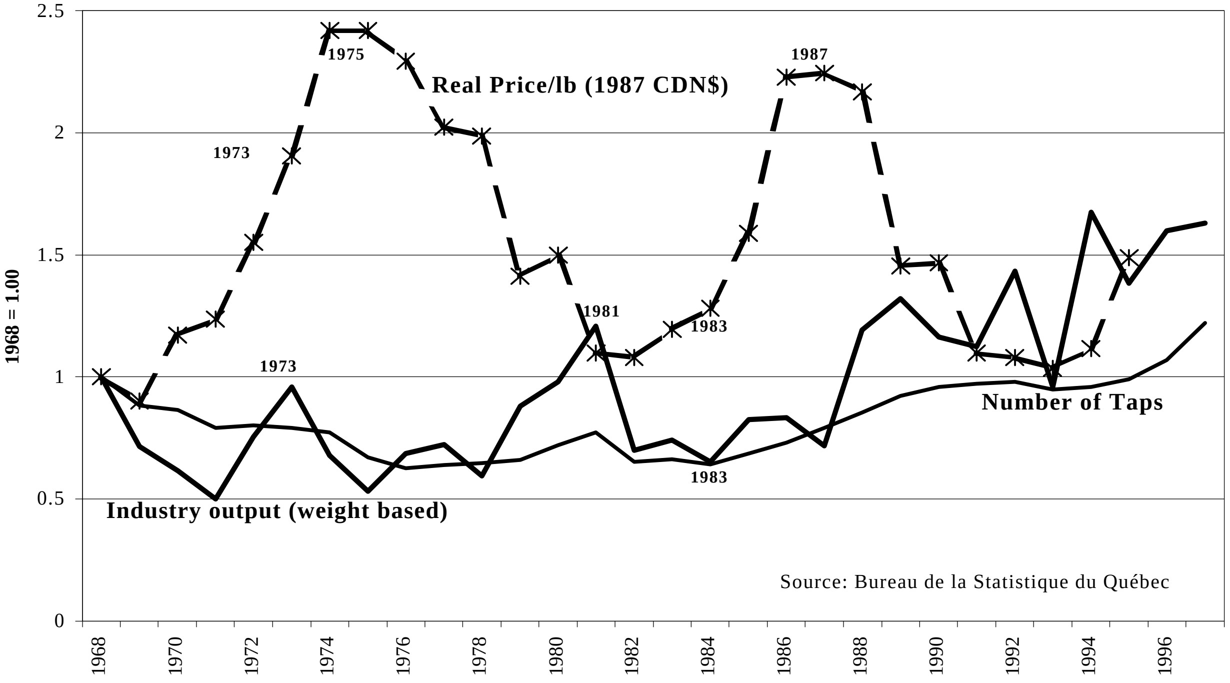
Sources: Manion (1981); Gagnon and Roy (1995).

Table 4 suggests that global warming predisposes dieback, while El Niño events may trigger it. This classification assumes a given chronology of stresses, but ecosystems are likely to present more complex interactions between stresses. They might have additive, synergetic or even antagonistic impacts on tree health. Dieback-triggering stresses might also become dieback-aggravating in conjunction with other stresses.

Some notable maple-adverse weather anomalies potentially caused by El Niño are: (i) mid-winter ice storms; (ii) mid-winter thaw-freeze episodes; and (iii) mild winters with little snow on the ground. As explained above, these anomalies can interfere with the maple sap harvest in any given year as well as damage the trees, or even kill them, and thus affect production for years to come through tree health. Indeed, ice storms can break branches and damage the bark of the trees, which will require high energy expenses to heal. Thaw-freeze episodes can trigger early burgeoning which is then abruptly interrupted. Frozen burgeons die and a new generation must later occur for the leaves to develop for the summer. Again, this demands more energy than usual from the tree. The leaves are then likely to be sparse, leading to a subsequent smaller storage of energy for the next winter. It is easy to see how it can take years for the trees to recuperate and how it can also gradually lead to death. In turn, a winter with early but then little snow on the ground might cause the tree roots to freeze, endangering the harvest for many seasons and even threatening the life of the tree.

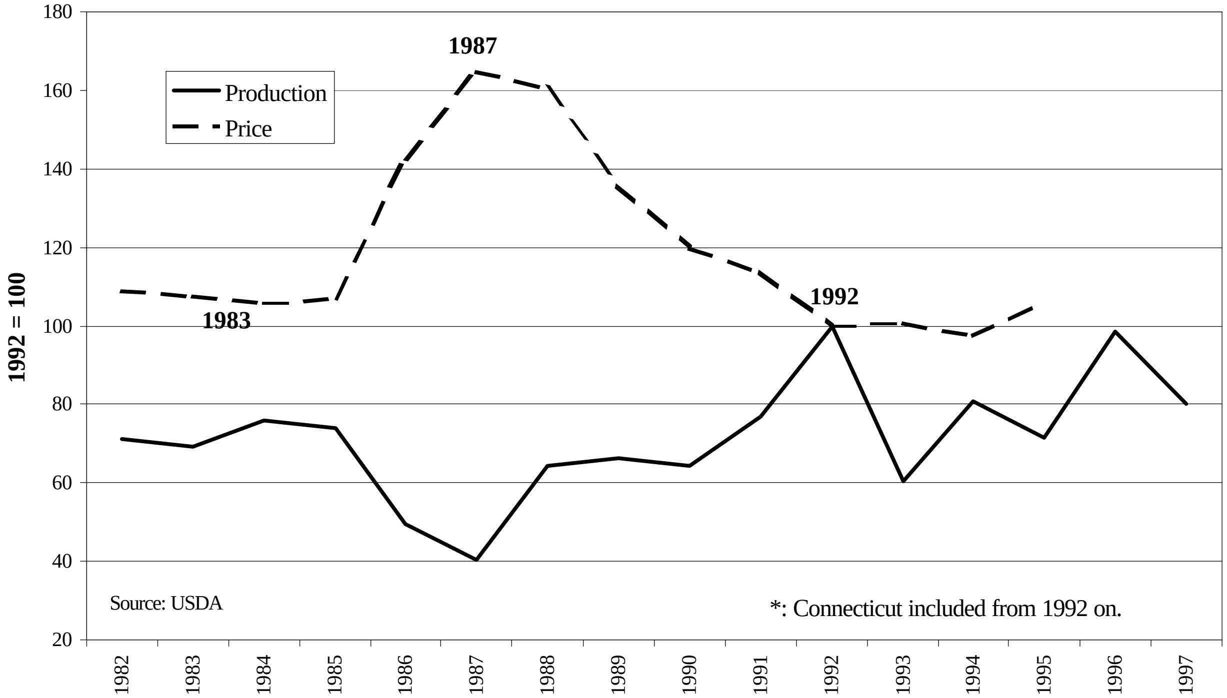
Climatic anomalies have been observed to trigger dieback that last for years before trees recuperate and become normally productive again, both in terms of tree growth and sap harvest. Sugar maples have limited tolerance to climatic stresses (Houston et al. 1990). Adverse soil humidity is also an important factor. Maples need humid soils rich in nutrients and the trees are made substantially more vulnerable by any departure from ideal soil conditions. Drought, frost and deep soil freezing are especially hard on maple trees. For example, unusual root freezing preceded severe dieback and tree mortality in New York, New England and Québec in the winters with little snow of 1979-80 and 1980-81, which were classified as normal ENSO years. The 1981 February thaw allowed two sugar seasons in some areas, one in February and the usual spring harvest. As a result, the 1981 harvest was higher than usual and real prices were lower than they had been in years (Figure 6), but tree energy levels were probably over-used by early burgeoning followed by frost and by the normal spring season, as well as by the two sugar seasons. All these weather-related events were followed by dieback in the following ten years or so, and maple syrup output was somewhat lower until the early 1990s. Real maple syrup prices increased substantially at the same time, peaking in 1987 (Figures 6 and 7). The precise impact of the 1982-83 El Niño event on maple syrup production is likely to remain unclear given these earlier adverse events. Its direct effect should have been seen on the 1983 harvest, but maple dieback had started a few years earlier at least in part because of weather anomalies that happened in non-El Niño years. Whether the 1982-83 El Niño event aggravated an already bad situation remains an open question.

Figure 6. Maple Syrup Production, Number of Taps and Price Indices in Québec, 1968-97



Source: Bureau de la Statistique du Québec

Figure 7: New England*: Production and Price Indices



Source: USDA

*: Connecticut included from 1992 on.

It was suggested that global warming might eventually offer more of an explanation as an underlying cause of maple dieback (Gagnon and Roy 1995). Not enough data are available for scientists to voice a clear opinion on this yet, but long run monitoring of forests and climate data may bring some answers to the recent waves of maple forest dieback. Global warming might trigger not only different weather patterns and variability, but also different defoliating insect dynamics, creating ecosystem disequilibria and making trees more vulnerable. Also, even though air pollution is not an important cause of dieback, it might become more so with global warming.

IV. INFLUENCE OF EL NIÑO ON THE MAPLE SYRUP INDUSTRY AND WELFARE EFFECTS

In order to elucidate the question "Does El Niño affect maple syrup production?," rather than the more general maple dieback, we have looked at the correlation between AR(1) de-trended maple syrup difference of output from the mean and ENSO event data (dummy variables for cold, normal or warm), looking alternatively at the same year, the previous year and the next-to previous year as well. However, we have found no statistically significant relationship. The analysis was performed at the smallest scale possible given the data available, that is at the state level for the United States and separately for the province of Québec and the rest of eastern Canada. Total output is clearly linked to demand and a structural simultaneous model of market clearing would be a better approach, if the required data were available for such an analysis. To circumvent this issue, we performed the same analysis on de-trended difference from the mean of yield-per-tap in Québec, since this datum was available for that region only. Correlations still were not statistically significant, however. Prices were not considered for analysis because, as for total industry output, not enough data were available for a simultaneous equations model. Also, the market structure changed over time (higher concentration in Québec with the development of marketing institutions), demand changed, especially for exports, and it would have been difficult to capture and separate the effect of these phenomena on prices from that of ENSO events.

We also used more detailed ENSO data to explain total industry output and per-taphole output. That data series is a new SST(sea surface temperature)-based index provided by the Japan Meteorological Agency (JMA) that serves as a proxy for the magnitude of ENSO events rather than just classifying them as cold, normal or warm. The JMA calculates monthly SST anomalies averaged for the geographic area 4N to 4S and 150W to 90W. A 5-month running mean is then applied to the data in order to smooth out potential intra-seasonal variations. Monthly values (i.e. magnitudes) were available to us for 1949 to mid-1997. The same kind of analysis as described above was performed, with averaged SST-based index for November-January, October-March or October-September of each ENSO year. Again, results were not statistically significant. Given the amount of manipulation the SST-based index goes through, and given the convoluted way in which maple sap harvest is affected by climate, these results were not surprising.

The lack of correlation between ENSO events and maple syrup production is not surprising since the maple dieback itself was not directly tied to it. The stresses triggering dieback in the early 1980s were climate anomalies, but they occurred in normal ENSO years. This complicates the task of finding a significant correlation: weather anomalies occur in non-El Niño years as well. Further analysis could namely incorporate local weather variables in order to control for weather anomalies in normal ENSO years.

One other factor that may help explain the lack of correlation between maple syrup production and ENSO events is that there is some "slack" in the production system. For example, in Québec, only 20 million tapholes existed in the early 1990s out of an estimated potential of 50 million (Babin 1995). In the U.S., production is generally more folkloric and even less intensive. Any type of damage due to the weather is hence likely to have limited impact on the market since other trees may be available for exploitation. Costs may rise since tapped trees are usually closer to roads and sugarhouses and with weather-related damages, trees that are deeper into the forest may be exploited. Also, some of the replanting costs, if needed will likely be passed on to the consumer. Hence, an increase in tree damage may not change the total industry production by much, but it is likely to increase the price of maple syrup. The increase in price, due to an increase in costs, is expected to be lower the more slack (substitutable trees) exists in the industry. Figures 6 and 7 seem to corroborate this suggestion, as real prices increased during the 1980-92 dieback episode. In New England, prices seem to vary inversely with production (Figure 7), while the inverse relationship is not as clear in Québec, where there may be more untapped, available trees in case of adverse conditions (Figure 6).

Table 5. Potential Effect of Weather Events on the Maple Syrup Industry

Climate anomalies	Effect	When recently?	El Niño?
Little snow	Roots freeze	1979-80 and 1980-81 (triggered severe dieback in NY, NE and QC)	NO
Mid-winter freeze-thaw	Early harvest possible, sometimes 2 in one year; Two burgeoning possible; Weakens the tree.	1980-81 (Feb 1981 thaw : 2 harvests) 1997-98	NO YES
Ice storms	Damaged trees.	1998	YES
Warm winter and especially warm spring	Shortened sugar season; Not enough T° difference between day and night; Insect epidemics	1998	YES

As mentioned earlier, the *quality* of the sap is also affected by the weather. Consistent time-series data are not available on bulk syrup classification. If they were, more statistical analysis could be conducted and perhaps some effect would show up in the quality of the syrup rather than the quantity produced. However, for such an analysis, the determinants of supply to the bulk market would also have to be modeled. Such an analysis could be conducted in the future, depending on data availability.

Since a statistically significant correlation has not been found between ENSO events and maple syrup production, we must conclude that the welfare effects on the maple industry have not been great so far. Also, given that the production level of the maple syrup industry has doubled in the last fifteen years, it is difficult to build a case to the contrary. However, if El Niño events became more frequent and if their magnitude continued to be important, the way it has been in the past twenty years, then some effects could be expected. While speaking with maple syrup producers in Québec in the fall of 1997, as the forecast of the most anomalous El Niño event ever had been made public, it was clear that producers were not aware of the impact it could have on their production. Since El Niño events were not directly linked to maple dieback in the past, this was not surprising. However, after the warm winter and the ice storms of 1998, producers are likely to be more aware of ENSO events in the future.

The possible impact of continuing strong El Niño events can be imagined as follows. The folkloric, traditional, "hobby-like" maple syrup production could be expected to continue along with the associated sugaring off parties that many generations have enjoyed in the past. This type of production does not require great investments like industrial-size production does. The development of the industry could be slowed down. This would mean less profit for producers, and less syrup on the market or less total utility for actual and future potential consumers. If El Niño events continued to be strong and frequent, government insurance programs similar to crop insurance programs in agriculture might be developed, although it is not likely in this era of deregulation. Special technical assistance and some emergency funds were made available to Québec producers in 1998 after the ice storm, but the weather event was exceptional and it is not clear how such situations would be handled in the future. Higher risks due to weather events with little prospects of increased insurance opportunities could result in less investment in the industry as there would be otherwise.

Indeed, few defensive activities are available for maple syrup producers when faced with anomalous weather event forecasts. While establishing their operations, producers could be even more careful than before about sun exposure, soil type and drainage conditions to make trees less vulnerable to weather shocks. Harvest efforts could be adapted to tree health, which might be affected by weather shocks. Also, maple syrup stock management is possible to alleviate the effects of harvest level, quality and price variability on inter-temporal profits and overall welfare. In the long-run, genetic research could help make trees more tolerant to climate variability. However, given the dependence of maple syrup production on the weather, genetic manipulation of seedlings that aims at making them more resistant to weather variability could change--positively or negatively--the quantity and the quality of the syrup produced.

Already established maple sugar operations have even less resources to decrease the negative impacts of weather anomalies on their production. Indeed in the short-run, once an operation is in place, all that can be done is the adaptation of harvest effort to tree health and sound adaptive management of inventories. As such, the value of ENSO forecasts to established operations is likely to be positive but small, even if a clear correlation between productivity per tap and ENSO events was eventually found from empirical evidence.

Only small overall welfare effects would nevertheless be expected from El Niño due to its potential impact on maple syrup production. This is so because the share of maple syrup production in the economy is very small to start with. Also, maple syrup is a source of sugar and as such, many substitutes exist for it; hence impacts on consumers are expected to be small. Maple syrup and its by-products are also marketed as luxury food items. Many other luxury food items exist, so again, impacts on consumers would be small. The most unique feature of maple syrup production includes some cultural and amenity values linked to the springtime sugaring off parties; this appears as the least substitutable characteristic of the maple syrup industry. Indeed, few forest-based activities exist at the time of maple sap harvest. In all likelihood, even *if* the development of the industry is slowed down because of ENSO events, this springtime ritual will remain as it does not involve great investment like the larger, more sophisticated exploitations do. The welfare impact, through the lack of substitute would be greater if this tradition were to disappear as well.

If we add global warming to this scenario, we would expect the bulk of maple syrup production to move north, where the climate will be more suitable to it (Bloomfield and Hamburg 1997). Past climate records and climatic models tend to conclude that global warming will cause temperatures to warm more during the night than the day. Given the cold nights and warm days required for a good sugar season, this is likely to decrease the number of days in the sugar season and perhaps also the volume of sap collected per day. Sugar maples need a good snow cover in the winter and they are vulnerable to mid-winter thaw and summer droughts, which may all be consequences of climate change. Some climate models also project that warming will occur more in the spring than in the winter. That would shorten the sugaring season even more (Bloomfield and Hamburg 1997). If such a scenario occurs over time, we can expect the sugar season to shorten and the maple syrup production geographic range to move north, making Canada even more of a market leader. We could expect the southern range of maple syrup production not to develop the way it has in certain regions of Canada in the past fifteen years. Warming weather is generally thought to have worse effects than cooling weather; if global warming occurs faster than the adaptation capacity of the ecosystem, tree diseases and defoliating insect are likely to adversely affect northeastern forests until a new ecological equilibrium is reached. This will also affect the quantity and quality of syrup on the market and we could expect prices to increase in the process.

V. CONCLUSION

In this paper, we first summarized up-to-date general knowledge about ENSO events. We then presented rather detailed information about maple syrup production and its industry. Then, we summarized the findings of previous studies about maple forest dieback that occurred in the 1980's. This was followed by an attempt to find the statistical influence of ENSO events on maple syrup production and productivity, as opposed to the more general dieback studies consulted. ENSO events are likely to affect maple syrup production since it is so sensitive to the weather. A statistically significant direct correlation between these events and either total de-trended syrup production or de-trended tap productivity has not been found in our analysis however. This may be because many other factors affect production, and weather anomalies that also occur in non-El Niño years can affect production. Further analysis could perhaps incorporate local weather variables in order to control for weather anomalies in normal ENSO years.Few defensive activities are available for maple syrup producers when faced with anomalous weather event forecasts. Long-run forest management decisions matter a great deal when weather anomalies are a threat to tree health. In the short-run, however, only adaptation of harvest to tree health after the fact, and inventory management, given a weather forecast, are possible to alleviate the effect of weather variability on profitability. Overall, maple syrup producers do not have many resources to decrease the negative impacts of weather anomalies on their production. As such, the value of ENSO forecasts to them is likely to be low, even if a clear correlation between production or productivity per tap and ENSO events were to be found in the future.

Small welfare impacts of El Niño weather events are expected due to its effect on maple syrup production. This is so because the share of maple syrup production in the economy is very small, because some maple tree excess capacity exists, and because of maple syrup products' substitutability (albeit imperfect) with other consumer products. Indeed, maple syrup has many substitutes both as a source of sugar and as a luxury food item. However, the most non-substitutable values of maple syrup production are the cultural and amenity values provided by the springtime sugaring off parties. Even if the development of the industry was slowed down because of ENSO events, this springtime ritual would likely remain as it does not involve great investment like the larger, more sophisticated operations do. Hence, these values can be expected to remain.

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