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MEASURING RETURNS TO TECHNOLOGICAL CHANGE: A CASE STUDY OF CONTROLLED-ATMOSPHERE STORAGE IN NEW YORK

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ERRATA SHEET

Y = Consumer disposable income, \$/month, deflated by the Consumer Price Index (extrapolated from a quarterly series)

S = Annual U.S. apple production less New York production, 100 million lbs.

D_{73} = Dummy variable, observations from March 1972 to September 1974 equal 1, all other observations equal 0.

The dummy variable for the spring of 1972 to the fall of 1974 was included after examining the residuals and noting a series of extremely high negative residuals in this period. The period was one of extremely unstable farm prices, attributed to the lifting of wage and price controls and to the Russian grain purchases. The R^2 for the harvest season equation is 0.67, and 0.55 for the storage season equation. A number of residuals other than those for the 1973 time period appear in the data as significant outliers. However, there is no theoretical reason to delete other observations through the use of dummy variables.

The estimated equations offer an interesting suggestion of the role of controlled-atmosphere storage on demand. The shift back of the harvest season demand curve because of controlled-atmosphere storage corresponds with a nearly equal shift to the right in the storage demand curve because of controlled-atmosphere storage. Thus, it would appear that total demand for apples was not affected by controlled atmosphere, but rather demand shifted from harvest season toward storage season and consumption became more equal throughout the year. This hypothesis was tested by running a pooled regression for harvest and storage months combined and including the controlled-atmosphere storage variable. The regression coefficient for the controlled-atmosphere storage variable was not significantly different from zero.

These demand shifts are presented graphically in Figure 8. The coefficients in the demand equations for the controlled-atmosphere storage variable are nearly the same, 0.066 for the harvest season equation and 0.061 for the storage season equation, and cannot be demonstrated to be statistically different. This means that the total annual demand for apples was unchanged by controlled-atmosphere storage.

Nevertheless, this interpretation of the model is difficult since it suggests that controlled-atmosphere storage caused a downward shift in the demand for harvest season apples. The line of causality is clouded because this is an incompletely specified model. Having controlled-atmosphere storage apples available should shift demand to the right for storage apples, and this shift could eventually make demand in the storage season equal to the demand in the harvest season since apples will be of the same quality in both time periods. However, controlled-atmosphere

PREFACE

The research reported in this publication is a contribution to Cornell University Agricultural Experiment Station Project 307 and to a national interregional project, IR-6, National and Regional Research Planning, Evaluation, Analysis and Coordination. This is also listed in that publication series as IR-6 Information Report No. 64.

One of the continuing questions facing society, legislators and administrators is the evaluation of the contributions of research supported by public funds and the ways in which these benefits are distributed across society. This study considers one of the important technological innovations which is not output increasing, but extends the useful storage life of fresh fruits and vegetables. In that sense it is a different type of agricultural innovation from that considered in most previous studies assessing associated costs and benefits.

The research carried out by Fred Cannon was part of an M.S. thesis project directed by Professors Randolph Barker and Bernard Stanton, Department of Agricultural Economics. Important sets of data were contributed from the personal files of Dr. Robert Smock, pioneer research scientist, who developed and tested much of the practical storage methodology required for this innovation. This study, if it has merit, is a tribute to Dr. Smock's creative energy and ability to recognize the potential significance of this innovation to both producers and consumers. The regression analyses were carried out with the assistance of Dr. W. G. Tomek who has made a number of studies of supply-demand relationships both for New York and the United States.

Jeffrey Charlesworth assisted in editing the original manuscript into its present form and checking some of the calculations. Mrs. Cherie Morse typed the final copy and did much to improve the visual quality of these materials.

B. F. Stanton
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by

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Introduction

Scientific research is a major source of growth for a modern economy. Developed countries, such as the United States, have achieved much of their affluence by investing billions of dollars in fundamental and applied research. Investments into research have increased the productivity of resources through technological advances. These increases in productivity free up resources for use in other production processes which expand the output capability of an economy.

Objectives

The objective of this analysis is to measure the net benefits to society from development of controlled-atmosphere storage of deciduous fruits by the application of research and extension over a span of approximately 30 years. The hypothesis for study is that returns to this research investment have been high. The methodology used presents some problems because controlled-atmosphere storage is not an innovation that increases production, but rather, one that allows a product produced in a period of three to four months to be marketed throughout the year without a reduction in quality.

Controlled-Atmosphere Storage

Each year considerable public funds go toward apple research in the United States. The USDA reported that over $22 million was spent nationally in 1974 by state agricultural experiment stations for research on deciduous fruit, of which apples are a major component. The resources invested by universities in California, New York, Washington, and Michigan represented almost half of this total. In New York, deciduous fruit research per unit of production exceeds that of any other state. As the most

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* This publication is based on a M.S. thesis by Frederick Cannon presented at Cornell University, "Measuring Returns to Technological Change: A Case Study of Controlled-Atmosphere Apple Storage in New York", August 1982.

important fruit enterprise, apples have received most of the research time and expenditure. New York research on apples has produced many new and superior apple varieties, as well as breakthroughs in production and storage. One of the significant breakthroughs has been the development of controlled-atmosphere (CA) storage for apples by Professor Robert Smock and associates at Cornell University. This procedure allows fresh apples to be kept up to eight months in storage while retaining their flavor and eating quality.

Controlled-atmosphere storage, an extremely successful innovation, was initiated over 30 years ago. Hence, it is now possible to observe much of the benefit flows from this research. Because the Experiment Station and the New York Crop Reporting Service were well developed when the research took place, reasonably accurate and reliable data on production, storage and utilization are available. Furthermore, because much of the research was confined to New York State during the early years of controlled-atmosphere storage, analysis on a state level is at least initially appropriate. This combination of data availability and regional application provides a rare opportunity for a benefit-cost analysis of returns to agricultural research.

Nevertheless, the analysis of controlled-atmosphere storage offers complexities and challenges. Most previous analyses of research projects in agriculture have concentrated on the production process and associated increases in output efficiency. However, controlled-atmosphere storage is a marketing breakthrough. Unlike a project such as hybrid-corn research or machine harvesting of tomatoes, controlled atmosphere storage simply maintains the fresh quality of a product across time and does not increase the production of a product or lower production costs.

If decision makers are going to use benefit-cost analysis in allocating resources to research, then they will need to be able to compare projects like controlled-atmosphere storage to projects like hybrid-corn research. Using methodologies compatible with different types of projects is important because each methodology has inherent problems in its application. Therefore, applying techniques to controlled atmosphere research, that were successful in measuring returns to production-increasing research, may be useful in considering other demand enhancing product related work.

Structure and Characteristics of the New York Apple Industry, 1949-1978

The structure of the New York apple industry is similar to that of other states. Clearly trends in production, use, varieties, costs and prices vary throughout the nation. The introduction of controlled-atmosphere storage in New York likely influenced some of these trends between 1949 and 1978. In addition, changes have taken place in both the supply and demand characteristics of apples over the same period of time.

Structure of the New York Industry

New York apple production, which nationally ranks second only to Washington, is important to the state in terms of both income and employment. The industry involves not only those people who produce the apples and the inputs for production such as fertilizers, insecticides, and machinery but also those who store, transport, and market the crop from the orchard to the supermarket. In addition, over 60 percent of New York apples are processed into juice, cider, applesauce, pies, and other products by processing firms, which comprise a large industry as well. Cash receipts from farm marketings of apples were just under $112 million in 1979, which ranks apple producers second to dairy farmers in terms of their receipts from farm products.

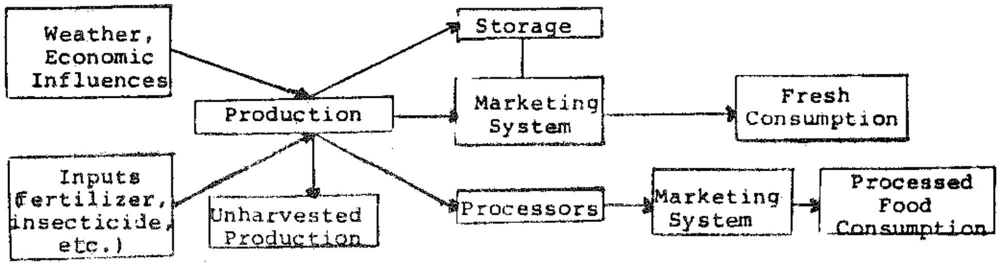
Apple growing in New York begins in April and lasts until harvest is completed in November. Throughout the harvest period (August-November) tree-fresh fruit are available to consumers. The remaining crop goes into storage or to processors.

Apples stored for out-of-season fresh sales are put in either conventional cold storage or controlled-atmosphere (CA) storage. Under conventional cold storage, apples are kept at consistently cold temperatures. This allows apples to be stored for marketing from one to five months after harvest although fruit quality declines over time. In controlled-atmosphere storage the conventional cold storage chamber is sealed, and the levels of carbon dioxide and ethylene in the room are regulated. Controlled-atmosphere stored apples, which can keep longer than apples in conventional cold storage, are usually marketed four to eight months after harvest. As expected, controlled-atmosphere stored apples marketed during the same months as conventionally stored apples receive a premium price.

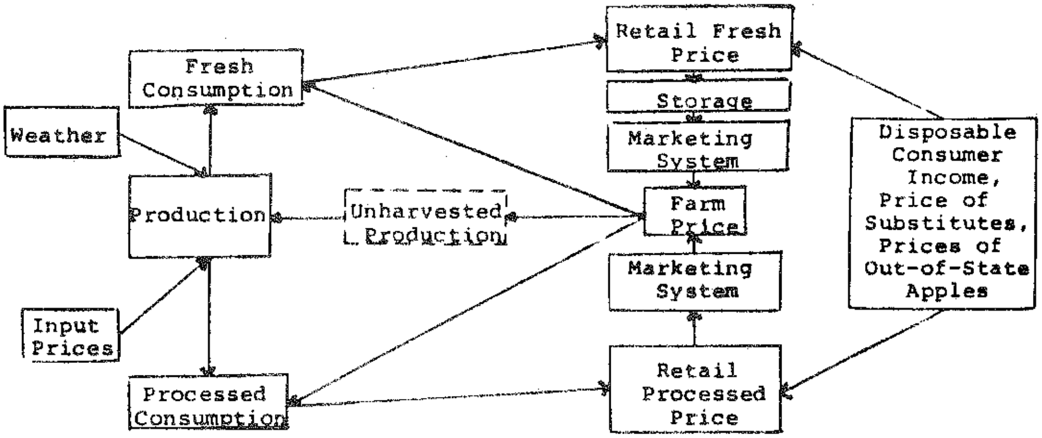
In most years, processors purchase about 60 percent of the New York State apple crop. This is a much higher percentage than in Washington where as much as 80 percent of their crop is sold fresh. This might seem surprising since eastern production is closer to major markets. However, this situation is a result of a developed processing industry, which requires a large percentage of production, and the east's relatively poor reputation with fresh fruit marketers. Some major fresh buyers have felt that eastern apples are of inferior variety, have less color, and lower quality. Since processors usually pay only a fraction of the fresh fruit price, New York growers receive a smaller value for the same production than do their western counterparts.

Figure 1 depicts the demand and supply structures of the apple industry and graphically presents factors which affect equilibrium price. The arrows show the direction of influence each factor is thought to exert. The simultaneity of the model is apparent since, for both production and price, lines of influence go in both directions. Exogenous influences (weather, input prices, disposable consumer income, prices of out-of-state

Figure 1. STRUCTURE OF THE NEW YORK APPLE INDUSTRY



A. Physical Flows (arrows show flow of goods)



B. Demand and Supply Structures (arrows show direction of influence)

Source: Karl A. Fox, The Analysis of Demand for Farm Products, USDA Technical Bulletin No. 1081 (Washington, D.C.: Government Printing Office, 1953), p. 10.

apples, prices of substitutes) come from outside the system and are not directly influenced by it. Starting from the left, exogenous factors such as input prices and weather, as well as the endogenous farm price (through quantities unharvested), affect production. Farm price, which is determined through the marketing of both fresh and processed apples, is influenced by production's effect on the amount of apples available for consumption. The other exogenous factors, such as prices of substitute products, enter the system through retail, processed, and farm prices. Figure 1, however, deals only with current year factors. It does not show the direct influence of current farm prices on production in future years.

Changes in Prices and Quantities

Apple production and price trends in New York have not always conformed to national patterns, but, instead, have often taken on a pattern peculiar to the state or the Northeast region.

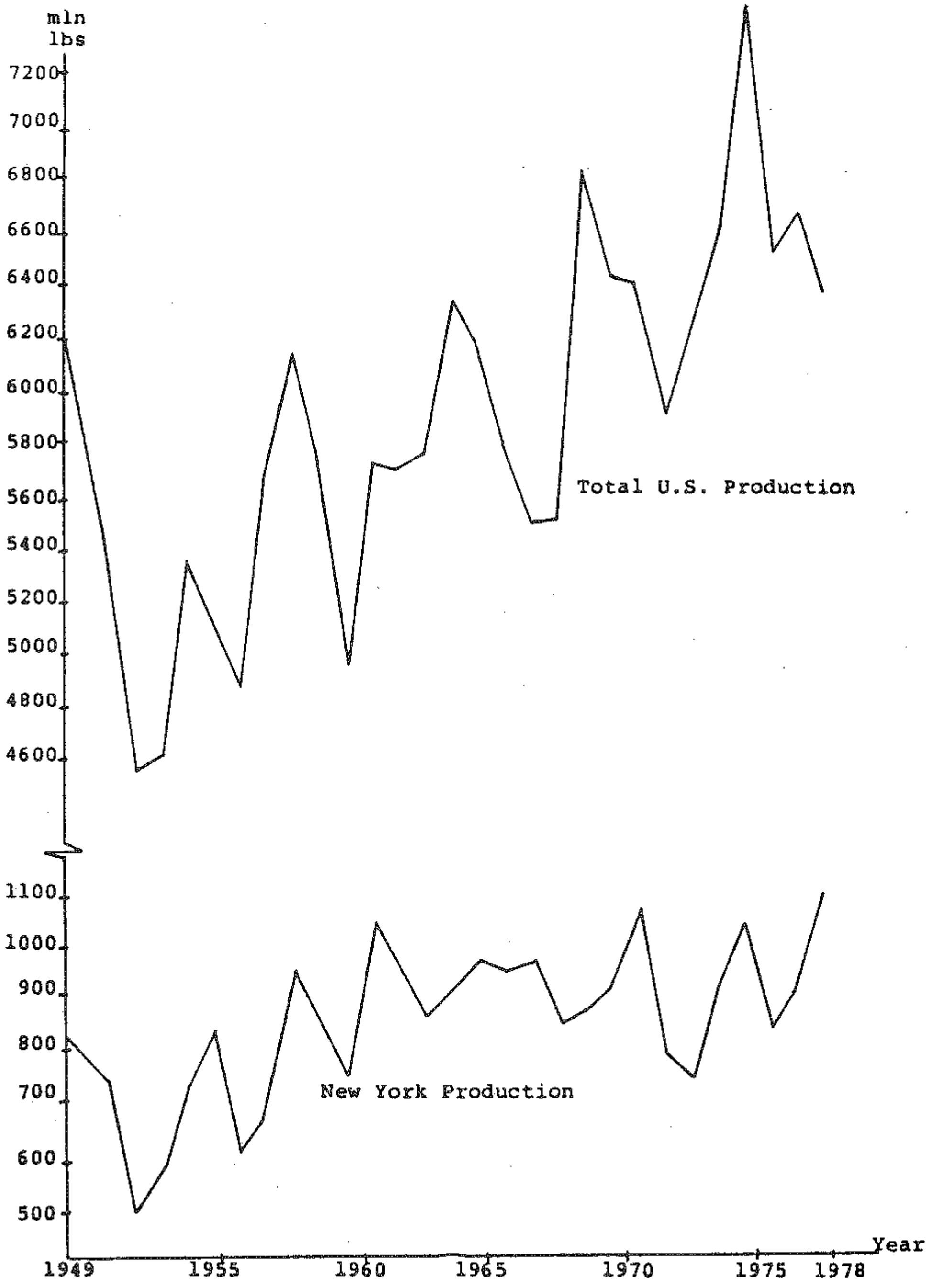
Since 1969, New York apple production has leveled off, while total U.S. production has risen sharply as a result of increased acreage put into production in the west, especially in Washington. This trend has been especially strong in the last ten years (Figure 2). From 1969 to 1977, average apple production in New York rose less than six percent from 908 million pounds to 913 million pounds. On the other hand, average production in Washington jumped 54 percent from 1,422 million pounds to 2,189 million pounds.

National trends in consumer preferences and technology have increased the amount of apples processed from 1949 to 1978. However, fresh sales have remained relatively stable, and when measured on a per capita basis, fresh apple consumption has decreased. In New York the trend is similar. However, processing takes a much greater percentage of the New York crop than it does for the United States as a whole (Figure 3).

Although fresh and processing sales have moved in different directions, the annual shift of each use is the same. Generally, an upward shift in fresh sales is accompanied by an upward shift in processed sales although the magnitudes are much different. The same is true of downward shifts. This would seem to indicate that long-run shifts in use are predetermined by long-run shifts in consumer tastes, and that annual production determines the short-term relationship of fresh to processed sales. Apple quality would account for some yearly shifts. A higher quality crop will have a greater percentage used for fresh sales because fresh apples bring premium prices.

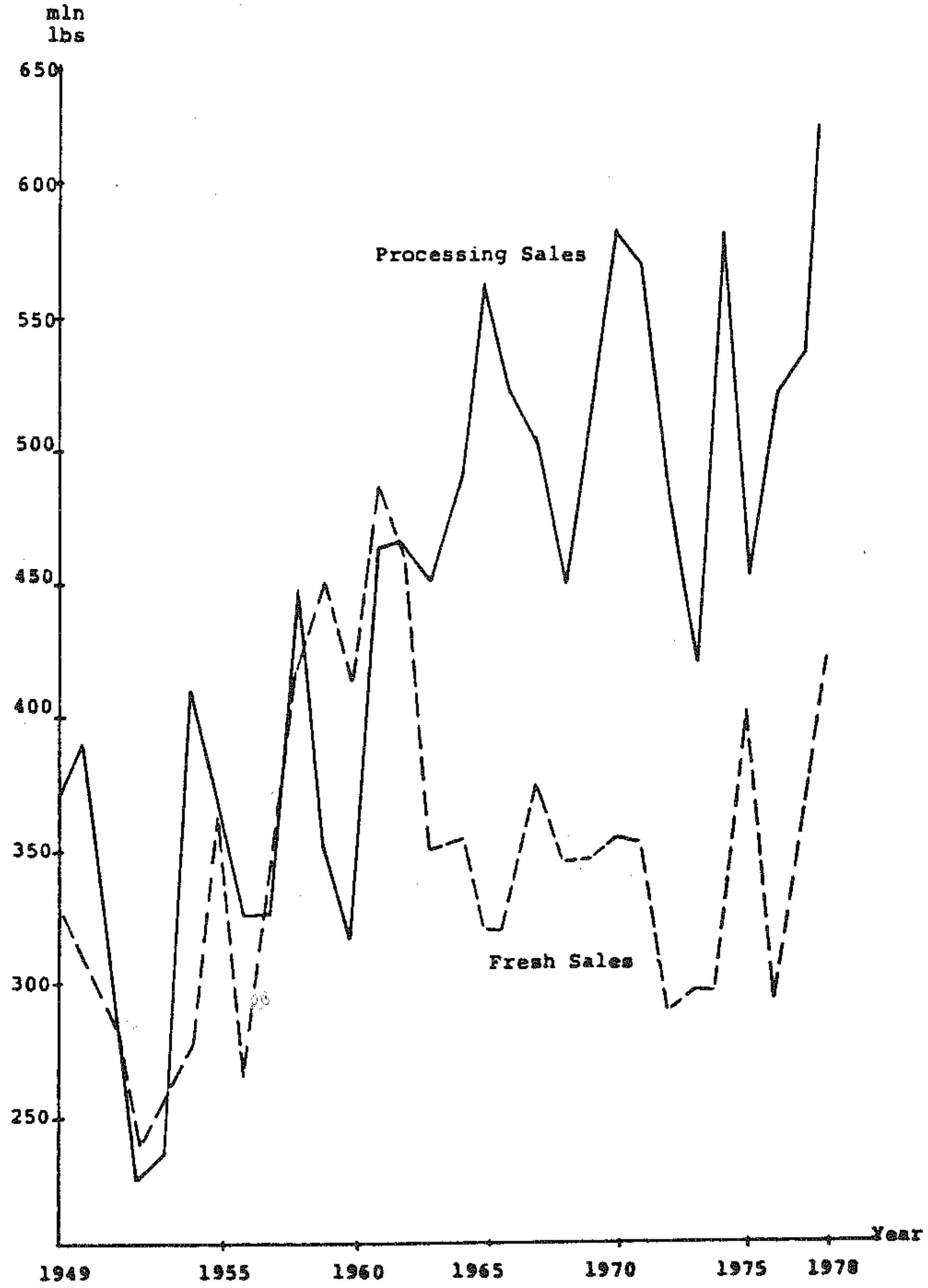
The average farm prices for fresh and processed apples in the United States and in New York have trended upward over time. However, prices for each type of utilization increased rapidly in the late 1960s. Much of the upward trend is caused by inflation, but in recent years the fluctuation depicted has been much greater than the general price trend. New York apples do not appear to carry a premium price for either fresh or processed sales over average U.S. prices. Rather, the New York prices seem to show slightly greater fluctuation than those for the U.S. as a whole. Even though some marketers feel that New York apples are of inferior quality, the recent New York average price for fresh apples has risen above the annual average U.S. price. The premium for New York apples may have developed in recent years as energy costs of transportation have given some advantage to eastern production.

Figure 2. APPLE PRODUCTION, U.S. AND NEW YORK STATE 1949 to 1978



Source: USDA, Agricultural Statistics, 1974 (Washington, D.C.: Government Printing Office, 1947); USDA, Agricultural Statistics, 1978 (Washington, D.C.: Government Printing Office, 1978).

Figure 3. UTILIZATION OF APPLES, NEW YORK STATE
1949 to 1978



Source: USDA, Crop Reporting Board, New York Agricultural Statistics (Albany, New York: Government Printing Office, 1979); USDA, Non-Citrus Fruits, Annual Summary (Washington, D.C.: Government Printing Office, 1949-1978).

Costs of Production

Although farm level apple price has been trending upward in New York during the past 30 years, the changes in costs and profitability of producing apples have had a complementary impact on the state's apple industry. The changes in production costs and profitability in New York account for much of the variation in production along with weather.

Technological advances have had an important impact on the costs of producing apples in New York over the past 30 years. New developments in breeding and orchard management techniques, improvements in farm machinery, fertilizers, and insecticides, combined with discoveries of growth regulators and spray-thinners, have significantly changed the structure of production costs. These costs have led to more concentrated and specialized production in New York in the areas best adapted for fruit production.

Another strong factor affecting the production costs of apples in New York is the relative costs of inputs. As in most industries, labor costs increased at a faster rate than most other inputs in the 1950s and 1960s. This change in relative labor costs is the basis for many of the labor-saving technological changes discussed above. From 1949 to 1975, the hours of labor used to grow an acre of apples decreased by 32 percent while yield rose 60 percent.

The rapid increase in energy costs in the 1970s is another relative price change that has affected New York apple production. The increasing energy costs of transportation are at least partially responsible for average New York apple prices having a premium over the average U.S. apple prices in the 1970s. However, as population has consistently been moving out of the Northeast since 1970, the relative importance of New York's regional market is diminishing.

Summaries of apple farm cost accounts suggest that growing costs remained at about half of total production costs throughout the 1949-1975 period. Although equivalent data on harvest and storage costs are not available, one would expect that, because of the development of controlled-atmosphere storage, storage costs have increased as a percentage of total costs over the years.

Land and labor productivity increased substantially over the period, but total productivity measured in terms of the value of resources used per unit of output improved only modestly because of the great increase in capital expenditures and purchased inputs. This substitution of capital for land and labor is typical of changes in most commercial farming operations during the same 30-year period.

Controlled-Atmosphere Storage

The most dramatic development in apple marketing since 1949 has been the introduction and implementation of controlled-atmosphere storage which allows apples for fresh sale to be kept for five to eight months and thus creates a high-quality apple for late-season consumption.

The first work on controlled-atmosphere storage originated in England in the 1920s, but it was Dr. R. M. Smock at Cornell University who was responsible for perfecting the new storage method for commercial use. Professor Smock's work at Cornell allowed New York to become the first area to successfully use controlled-atmosphere storage ten years before the rest of the U.S. implemented the new technology.

The controlled-atmosphere storage process slows the respiration and ripening of apples by regulating the temperature and gaseous atmosphere in the storage chamber. Low temperatures, the fundamental principle of cold storage, slow the respiration and ripening of fruit. Lowering the amount of oxygen and raising the amount of carbon dioxide around the apples also retards respiration and ripening. Controlled-atmosphere storage combines all three of these principles.

Monthly storage data from 1949 to 1975 show a progressive increase in the amount of apples in storage in later months from March to June which can be attributed to the superior capacity of controlled-atmosphere storage facilities to maintain fruit quality. Each year shows an increase in the quantity of apples put in controlled-atmosphere storage and a decrease in the amount of apples put in conventional cold storage. In addition, the percentage of apples in storage in the later months continuously increases until 1965. After 1965 it appears that controlled-atmosphere storage reached full economic use with roughly the same percentage of apple production in storage for the same period of time in 1975 as in 1965. Because controlled-atmosphere storage put more high-quality apples on the market in later months, May and June prices between 1949 and 1969 have leveled off or even decreased in relation to early season prices. In 1949 the June price was 43 percent above the November price while in 1975 the June price was only 25 percent above the November price. Prices still rise in later months because of the cost of storage and the improved quality of controlled-atmosphere stored apples.

The growth of controlled-atmosphere storage and its impact on price demonstrates the rapid acceptance and implementation of this new technology. Farmers do not accept new methods merely because they are new. Growers saw high prices for good-quality apples late in the season, and built storage that allowed them to capture some of the benefits from those high prices.

Summary

Many changes have taken place in the New York apple industry over the period 1949-78. Production has been amazingly stable for the past 20 years despite rising prices. A number of factors, both positive and negative, have brought about this situation.

On the positive side, three main factors which have benefited New York producers stand out:

1) The well developed processing industry in New York and the state's large production of apples for processing has been supported by consumers' increasing consumption of processed apples at the expense of fresh apples;

2) The state is closer to major markets than other large production areas and recent upswings in transportation costs have increased this advantage;

3) Controlled-atmosphere storage gave the state a technological advantage early in the 1950s and 1960s; other states lagged behind New York in implementing the process. In recent years, however, other producing regions have fully implemented controlled atmosphere techniques.

Negative factors center around two major points:

1) The competitive edge of western growers in producing highly finished red apples and

2) The relative decline of eastern market power.

In short, despite rising prices and proximity to markets, New York apple growers have lost part of their market share, especially in fresh apple production, to their western competitors who have lower production costs.

Methods to Measure Returns to Research

Agricultural economists have used numerous techniques to try to measure the returns to agricultural research. Although most work in this area has centered on measuring returns to production-oriented research, this analysis looks at a technology which changed the quality of a product across time. As a result, previously developed methodologies had to be adapted to measure returns to a technology which maintains quality of fresh produce over longer time spans.

Methodologies previously used in ex-post analysis to measure returns to agricultural research can be grouped into three major categories:

1. The use of regression analysis to estimate a regression coefficient for a variable representing investments in research in a Cobb-Douglas type of production function.
2. The measurement of resources saved by new innovations.
3. The measurement of consumer and producer surplus used in conventional benefit-cost analysis.

Outside these classes, there are two additional approaches; one estimates the impact of new technology on national income, and the other measures the nutritional impact of agricultural research [9].

The production function approach was first used to estimate returns to aggregate expenditure on agricultural research in the United States [5]. A Cobb-Douglas production function was estimated for aggregate agricultural production through the use of ordinary least squares on log-transformed data. Unlike the ordinary Cobb-Douglas equation which estimates production through the use of the independent variables of capital, land, and labor, a new variable was included to represent technology. From the estimated coefficient of the technology variable, the marginal product and internal rate of return to investments in technological change can be derived. Later, this same methodology was used to estimate returns to individual research projects [10].

The Cobb-Douglas function used to estimate returns to investments in technological change has usually been of the form:

$$Y = AX_1^{\alpha 1} X_2^{\alpha 2} X_3^{\alpha 3} X_4^{\alpha 4} + e$$

where

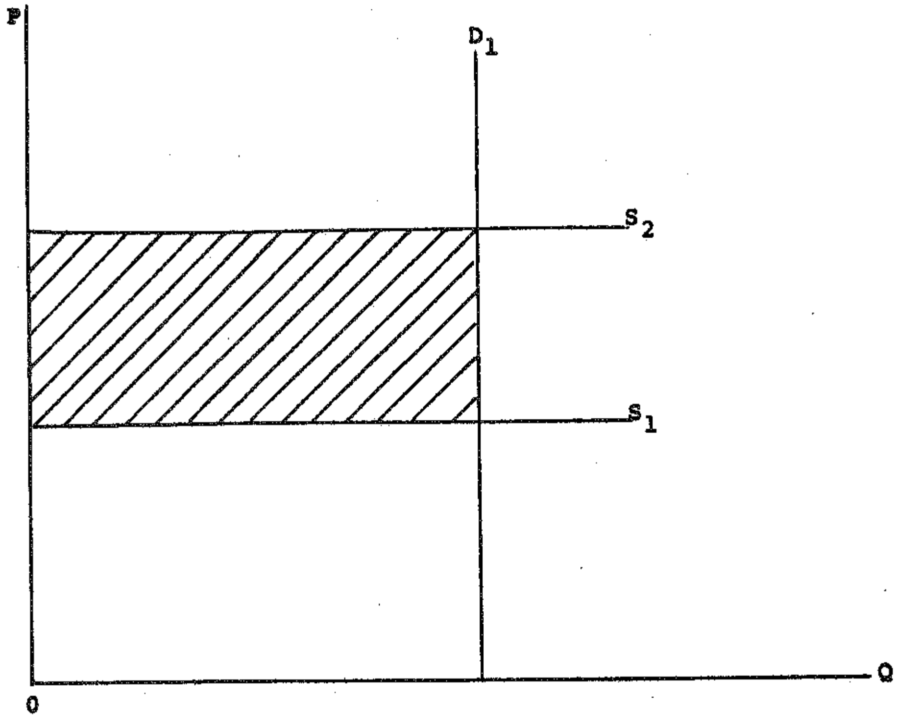
x_1, x_2, x_3 = variable inputs (land, labor, capital)
x_4 = expenditures on research

An extension of this analysis used this approach to measure the distributional impacts of investments in technology [3].

The second technique, the resources-saved approach, also called the index numbers approach, was first developed by Schultz to measure returns to technological investments in U.S. agriculture as a whole [11]. The value of inputs saved through more efficient production techniques was calculated and compared to costs of research and development [9]. Inputs saved were estimated as the difference between the dollar amount of inputs needed to produce a given output in another year. Because relative prices change over time, an index number problem arose in measuring the value of inputs saved over time. This problem was dealt with by creating upper and lower limits for the resources saved. In later years this approach was extended for use in measuring returns to technological investments in individual commodites, such as corn or citrus fruit research.

Essentially, this approach is a simplified version of the benefit-cost technique. In effect, the resources-saved approach calculates the increase in consumer surplus resulting from the savings in inputs from investments in research with the assumptions that supply is completely elastic [9]. Figure 4 shows this process, diagrammatically. Over time the supply curve shifts downward as the same supply of goods is produced at a lower cost. Because demand is assumed to be completely inelastic, benefits can be measured as the output times the decrease in costs associated with production (i.e., resources saved).

Figure 4. CONSUMER SURPLUS IN THE RESOURCES SAVED APPROACH



The third approach, which uses the conventional approach of benefit-cost analysis, involves a partial equilibrium analysis in which the returns to research investments are measured by the shift in the supply curve caused by resulting technological advances. Since, in a partial equilibrium model, a technological advance (resulting from successful research) shifts the supply curve to the right, returns to consumers and producers can be measured using the concepts of economic surplus.

Figure 5. CONSUMER AND PRODUCER SURPLUS

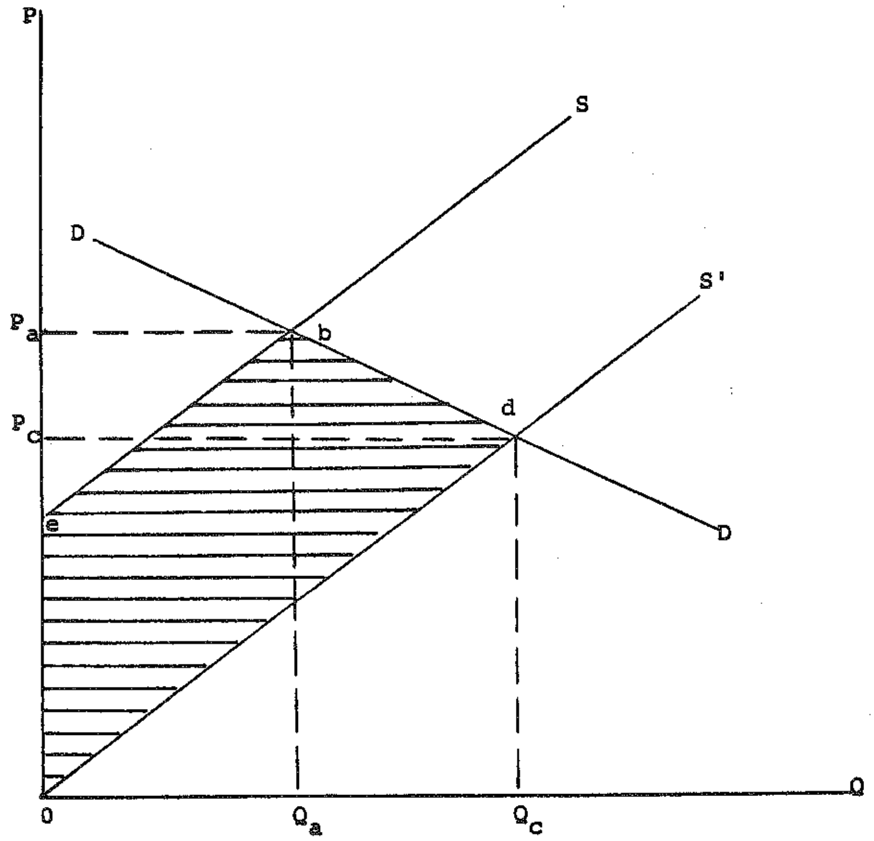


Figure 5 presents this concept, graphically. Before any technological change occurs as a result of research, the equilibrium price and quantity are P_a and Q_a. With an outward shift of the supply curve (from S to S'), as a result of the technological advance, the equilibrium price and quantity move to P_c and Q_c. Gains to consumers can be measured by the amount of consumer surplus generated, that is, the area $P_a bdP_c$. Returns to producers can be measured by producer surplus, which is the area $P_c d0$ minus the area $P_a be$. If we assign equal weights to producer and consumer surplus, then the returns to an investment in research can be measured by the area of $P_a bdP_c$ plus $P_c d0$ minus $P_a be$ (the additional consumer and producer surplus generated) which, in sum, is equal to ebd0 (the shaded region on the graph). If these areas can be measured, then the average return to a research investment can be derived by dividing the area ebd0 by the dollar sum of the investment. Also, the distributional gain between producers and consumers can be measured.

Many different formulas have been used to measure the areas described above. In each case, the price elasticities of supply and demand must be estimated, and shadow prices (marginal costs) must be used rather than market prices because of such devices as price supports and export quotas. Scobie analyzed four different measurement methods and reported that each method yielded a different answer to two crucial policy questions:

1. Would consumers or producers benefit more?
2. Would producer surplus be positive?[12]

Linder and Jarrett reported that each analysis has to make and justify an assumption about the type of supply shift [7]. Figure 5 shows a parallel shift. But, under different assumptions, the shift could have been pivotal, divergent, or convergent. Linder and Jarrett went on to show that depending on the assumption made about the supply shift, the measurement of net benefits could vary up to 300 percent.

To provide a complete view of the effects of technological change induced by research on employment and returns to factor inputs, this partial equilibrium analysis should be expanded so that general equilibrium considerations can be taken into account. It is argued that in the general equilibrium framework, technical change which affects the level of one output will affect the relative prices of all other inputs and outputs [4]. This change in prices can lead to the reallocation of resources which can offset the direct effect of new technology on productivity. Bieri, deJanvry, and Schmitz concluded that through analysis of general equilibrium conditions, "one cannot say whether technological change, regardless of the sector in which it occurs, is beneficial or detrimental to society" [3]. All can be made better off only if appropriate redistribution takes place. The difficulties inherent in making empirical measurements of all the various factors affected by a change in one partial equilibrium condition are evident. Therefore, economists are forced into a "soft" analysis of the resulting general equilibrium conditions. Looking at trends in factor prices and which variables are affected by a shift in supply, has proven useful.

Application to Controlled-Atmosphere Storage

In deciding which general methodology to use in any analysis, it is important to see how well the method fits with what one is attempting to measure. Since controlled-atmosphere storage is a marketing rather than a production breakthrough, the benefits do not come from a decrease in resources used, but rather a better distribution of apples for consumer use throughout the year. This distinction makes it difficult to apply both the production-function approach and the resources-saved approach. The production-function approach has been used to measure returns to research for specific crops (e.g., returns to corn research, returns to poultry research) and not to measure specific innovations.

This is because all research investment done on a commodity needs to be included in the production function. Additionally, since more of the benefits from controlled-atmosphere storage affect distribution, not production, it is theoretically difficult to base an estimate of returns on a production function. The resources-saved approach also has theoretical problems in application to controlled-atmosphere storage because the major benefits were not from resources saved but from an increase in resource investment to get better distribution over time for consumption. The only methodology that can deal with the impacts of controlled-atmosphere storage is the benefit-cost analysis approach which requires measures of consumer and producer surplus.

In a partial-equilibrium analysis, controlled-atmosphere storage shifted the supply curve for fresh market apples to the right during the late spring and summer months. Supply shifts produce consumer and producer surpluses. If these concepts can be measured, then the return to a research investment can be derived by dividing the sum of producer and consumer surplus for relevant time periods by the dollar sum of investment. Further, the distributional gain among producers and consumers can be measured.

Some theoretical and practical considerations complicate the analysis if this approach is to be used to measure returns to controlled-atmosphere storage. The type of supply shifts must be determined. Because controlled-atmosphere storage not only allowed more apples to be available in spring and summer months but also put a higher quality apple on the shelves, some outward shift in demand must be considered.

Most benefit-cost studies of agricultural research analyzed innovations which affected the production rather than the marketing process. However, one study did estimate a benefit-cost ratio for potato storage research in Idaho [1]. The benefit measured the amount by which this research had reduced losses during storage and improved the recovery rate of stored potatoes. This was a measure of resources saved by marketing innovations. The major benefits derived from controlled-atmosphere storage, however, come from putting an improved product (spring and summer apples) on the market, rather than from saving apples that would otherwise have been lost in storage.

A number of economic analyses of controlled-atmosphere storage have been undertaken. Although not based on the benefit-cost approach, they are important to this project because different methods were developed to maximize producer returns to controlled-atmosphere storage. Each of the studies attempted to determine optimal storage facilities and marketing patterns for producers to maximize profits. Each also helps by specifying demand and supply schedules for analysis.

Lee and Jack attempted to determine if controlled-atmosphere storage use should be increased in the Appalachian District (fruit production areas in Maryland, Pennsylvania, Virginia, and West Virginia) to improve profitability of fruit production [6]. Their method consisted of determining whether an average producer (one who could fill a storage facility of 100,000 cartons) would increase profits by using controlled-atmosphere storage instead of regular cold storage. They compared increased building and operating expenses to the increase in revenue that would accrue from selling apples in later months using controlled atmosphere facilities for a five-year period. This analysis was done assuming the farmer put varying amounts of his 100,000 cartons in controlled-atmosphere storage. The study determined that the use of controlled-atmosphere storage would have increased the farmer's net present value during the five years 1968-1972. The methods followed in the study were straightforward. Increases in costs from using controlled-atmosphere storage facilities were estimated from data gathered in earlier special studies. Estimates of increased revenues resulting from controlled-atmosphere storage were calculated from the price differential between late season controlled atmosphere apples and early apple marketings.

Moffett [8] did a similar study for McIntosh apples in the New England-New York area, employing a quite different methodology. The study attempted to determine the optimal rate of moving apples from storage to market channels. First, demand functions for McIntosh apples in the region were estimated for each of the nine marketing months, September through May, using 1947 to 1961 data. As a second step, cost relationships were derived for each marketing month. Since using this model assumes market power (the ability to control supplies between time periods), net marginal revenue, rather than demand schedules, were used to allocate supplies across marketing months. Subtraction of cost functions from demand functions provided net demand relationships. Once net demand was determined for each of the nine months, optimal allocations were determined by the use of quadratic programming operating within a price discrimination framework. Optimal allocations for each year of the study period can then be compared with actual marketings. A crucial assumption in this analysis is that apple producers unite to exercise necessary market power.

Ben-David and Tomek used similar methods to optimize marketing allocations of New York apples across time [2]. Again, different demand schedules in different time periods were used to determine the optimal seasonal marketings. The idea was, that if demand schedules differ across time, then an optimal allocation of apples should take those demands into account. Ben-David grouped the nine marketing months into three-month intervals. The price flexibility (or price-elasticity-of-demand) coefficients were estimated for each marketing quarter using regression techniques. These demand schedules were used with storage costs data to solve for profit-maximizing seasonal allocations of apples. These profit-maximizing allocations were then compared to actual allocations to attempt to show how allocations could be improved.

In developing a benefit-cost analysis of controlled-atmosphere storage research, supply and demand schedules for fresh market apples must be estimated so that consumer and producer surpluses can be derived. The three studies discussed above help in the specification of the demand and supply schedules for this study. Also, these papers give a better understanding of how benefits from controlled-atmosphere storage flow to producers and consumers.

Methodology

The primary goal of this methodology is to develop a procedure to measure returns to controlled-atmosphere storage which allows a distribution among producers and consumers. A possible way to do this is to measure returns to producers directly through estimates of price-elasticities-of-demand (price flexibilities) and to measure returns to consumers through consumer surplus using the same flexibilities. This approach allows the use of a partial equilibrium model without some of the difficulties imposed by estimating separate supply functions necessary to derive producer surplus. These returns to consumers and producers can then be compared to the expenditures on controlled-atmosphere storage research, to come up with a benefit-cost ratio.

Since controlled-atmosphere storage was first introduced in New York in the late 1940s, a benefit-cost analysis using a discounting technique and thirty year set of data should adequately represent the total flows of benefits and costs. The first step in this analysis required estimation of the price-elasticities-of-demand for seasonal time periods, which reflect the different types of fresh apples sold (tree-fresh, regular stored, and controlled-atmosphere stored). This can be accomplished by estimating periodic demand functions using linear regression and time series data. The model Ben-David and Tomek [2] used for each time period is:

$$P_i = a_{oi} + b_{oi}\, Q_i + c_o Y_i$$

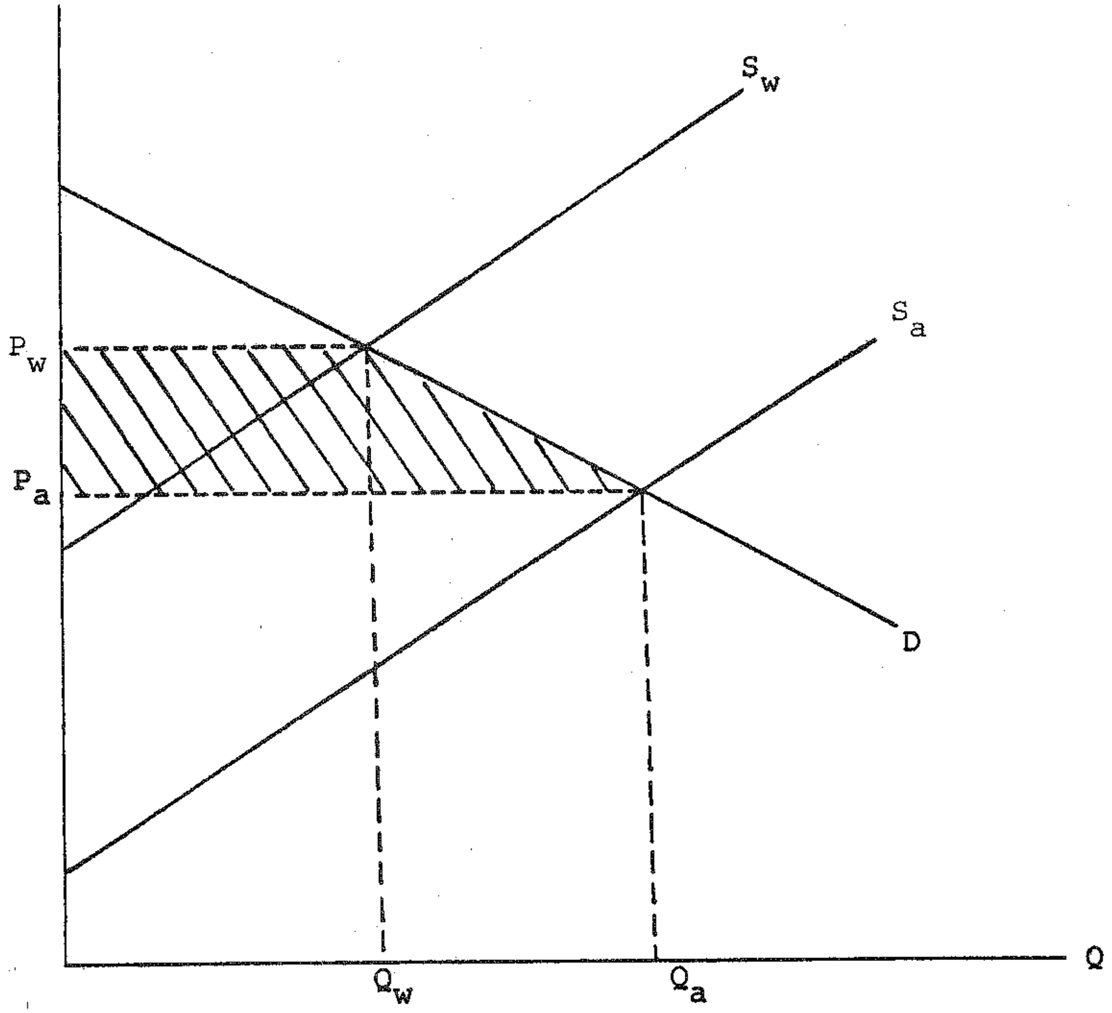
where

P_i = price in quarter i
Q_i = quantity in quarter i
Y_i = consumer disposable income

Other variables which affect demand such as competing product prices should be included in the model; nevertheless, this model or a similar one, can be used to estimate price flexibilities. As Ben-David and Tomek [2] demonstrate, there is little hope that demand schedules remain constant over a 30 year period. As a result, this analysis studies shifts in demand over time.

The next step is to estimate the supply shift resulting from controlled-atmosphere storage in each period. One must assume controlled-atmosphere storage did not affect the annual production of apples for fresh sale in New York State. Although this seems a rather heroic assumption, production of apples for the fresh market was stable over the time period. Using this assumption one can estimate the flow of apples in the absence of controlled-atmosphere storage for any year. This can be accomplished by applying the monthly marketing percentage computed for the years before the introduction of controlled-atmosphere storage to the production of any of the following years. Thus, estimated marketings without controlled-atmosphere storage can be compared to actual controlled-atmosphere marketings. The price without controlled-atmosphere storage can be estimated using the estimated price flexibility. The percent change in price will be determined by the percent change in quantity times the price flexibility.

Figure 6. CONSUMER SURPLUS



Estimating consumer surplus is simplified because all the necessary variables have been estimated. Consumer surplus for any time period is measured by the amount of increase in the area under the demand curve and above the supply line, generated by an outward shift in the supply curve. This is a measure of the change in the amount consumers would be willing to pay for apples in any time period, less the amount they actually pay. Using the variables discussed earlier for any seasonal period, change in consumer surplus is measuredby the shaded region shown in Figure 6. Algebraically,

$$\text{Consumer Surplus} = Q_w(P_w - P_a) + 1/2(P_w - P_a)\ (Q_a - Q_w)$$

this equation assumes demand is linear between the two equilibrium points. It is important to note that consumer surplus is negative in the early season because controlled-atmosphere storage has allowed producers to hold off delivery of apples until late months, which shifts the supply curve backwards.

The estimate of producer surplus can be derived using the same variables. The change in producer revenues resulting from controlled-atmopshere storage can be estimated using the formula:

$$\Delta R = Q_a P_a - Q_w P_w$$

where

ΔR = change in revenue
P_a = actual price
Q_a = actual quantity
P_w = estimated price without controlled-atmosphere

$$\frac{Q_w - Q_a}{Q_a}\ f\ P_a$$

f = price flexibility
Q_w = estimated quantity without controlled-atmosphere

To get net producer benefits in any time period, the increased costs that result from controlled-atmosphere storage must be subtracted from ΔR. The costs of controlled-atmosphere storage can be estimated using previous studies on costs of storage and costs of production. In the early season Q_w will be greater than Q_a, and in the late season the reverse will be true.

Demand Equations

This study used data related to farm level demand for apples for the period 1949 to 1978, and included monthly figures whenever possible. USDA publications provided monthly farm-level fresh apple prices for New York. These prices were deflated by the Consumer Price Index. The New York State Crop Reporting Service supplied monthly quantities of fresh apple sales. Both the price and quantity variables are presented in Tables 1 and 2.

After determining the two major variables, price and quantity, estimates of seasonal demand were considered. Four possibilities were attempted: (1) monthly; (2) quarterly; (3) three seasons: harvest from July to October, cold storage from November to February, and controlled-atmosphere storage from March to June; and (4) two seasons: harvest from July to November, and storage from December through June. Theoretically, the three-season approach seemed best since three types of apples are marketed: apples direct from farms, cold-storage apples, and controlled-atmosphere-stored apples. Not enough degrees of freedom and variability were available for monthly estimates of demand. Analysis of scatter diagrams of the price and quantity data showed that the two-season approach appeared to most nearly approximate the data. Intuitively, this makes sense since consumers may have a demand for farm-fresh apples from August through November that differs from demand during the rest of the year.

Monthly prices and quantities for 1959 to 1968 are plotted in Figure 7. As shown on the figure, the two lines drawn are the least squares estimates of the equation $P = a + bQ$ (the simple demand equation) for the two seasons. The slope of the storage season equation is steeper than that of the harvest season equation. No apparent consistent shift was observed during other times of the year. Further, the July observations showed no consistent pattern with other harvest season observations.

Various regressions were run for different lengths of seasons. The division of the year into two seasons, harvest from August to November, and storage from December through June provided the most consistent results. The best fit was obtained with December in the storage season rather than in the harvest season--a fact that was not evident from the scatter diagrams.

A number of other factors also influence demand for New York apples:

1. Consumer disposable income has a positive effect on demand for apples.

2. There are a number of substitutes for New York apples. The most obvious are apples from other regions in the United States.

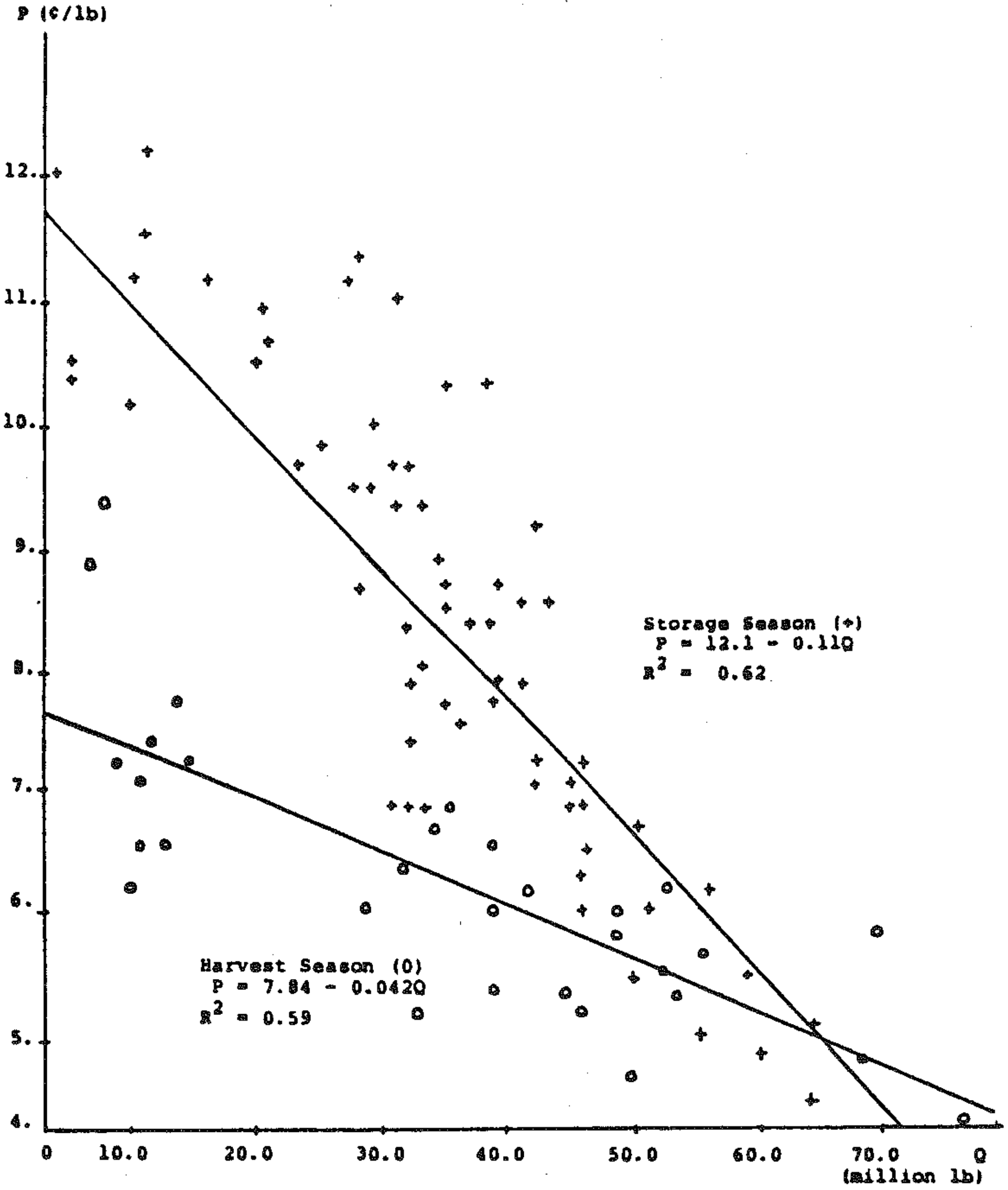
Table 1. MONTHLY AVERAGE FRESH APPLE PRICE, NEW YORK, 1949-1978

Crop Year	Jly	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
							(¢/pound)					
1949	6.0	4.0	3.3	3.1	3.1	3.1	3.2	3.2	4.4	4.4	5.0	-
1950	6.2	5.4	4.6	3.6	3.6	4.2	3.9	3.9	3.9	3.3	3.3	-
1951	2.6	4.6	3.3	2.9	3.6	4.2	4.3	4.5	4.9	4.9	5.4	-
1952	5.4	5.7	5.5	6.0	6.4	6.7	6.8	6.7	7.4	7.6	7.0	-
1953	6.0	6.5	5.8	5.7	6.2	6.7	6.4	6.4	6.7	7.1	7.7	-
1954	5.7	6.7	5.2	5.0	5.2	5.6	5.4	5.1	5.4	5.4	5.6	-
1955	6.0	6.0	3.7	3.8	4.4	4.6	4.5	4.4	4.3	5.4	5.4	-
1956	7.1	6.7	6.2	5.7	6.4	6.9	6.7	6.8	7.6	7.1	7.1	7.1
1957	7.1	6.8	4.2	3.9	4.3	4.5	4.4	4.5	5.7	7.0	7.1	7.1
1958	6.3	6.3	4.3	3.8	4.3	4.4	4.4	4.5	4.5	4.5	5.0	5.0
1959	6.2	6.2	4.0	3.8	4.4	4.8	4.8	5.2	5.5	6.0	6.4	6.9
1960	6.4	6.4	5.1	5.2	5.4	6.1	6.2	6.9	7.5	8.3	10.0	10.7
1961	6.4	6.4	4.8	3.9	4.0	4.4	4.4	4.9	6.0	7.7	8.9	9.5
1962	6.9	6.9	4.6	4.3	4.4	5.4	5.6	5.7	6.2	7.6	7.9	9.5
1963	6.4	6.4	5.5	5.2	6.2	6.5	7.1	7.7	8.1	8.8	10.0	10.7
1964	6.0	6.0	5.0	5.1	6.1	7.1	6.9	7.9	7.9	9.0	10.0	10.7
1965	5.7	5.7	4.8	5.6	6.4	7.5	7.1	6.4	7.4	9.5	10.0	10.7
1966	7.3	6.2	5.8	5.2	6.2	7.1	7.7	7.1	8.5	9.4	9.6	10.0
1967	10.0	9.2	6.6	5.7	6.5	7.0	7.2	8.3	9.3	10.4	11.3	12.3
1968	12.0	9.0	7.0	6.3	8.8	9.0	9.8	10.2	10.7	11.0	11.6	12.0
1969	13.0	9.0	7.1	6.5	7.1	7.3	7.3	7.4	7.5	7.6	8.0	8.5
1970	9.0	6.5	6.5	6.0	6.0	6.2	6.5	6.3	6.5	6.5	9.0	9.0
1971	9.0	9.0	7.5	6.5	5.5	6.5	6.4	6.6	6.2	6.5	7.0	8.6
1972	9.8	9.8	8.7	7.5	8.7	9.6	10.0	10.5	11.0	12.0	13.5	13.0
1973	14.0	14.0	11.7	11.3	13.6	13.8	14.5	15.0	15.0	15.5	15.5	15.0
1974	13.5	13.5	12.8	11.3	10.3	10.8	11.4	12.2	13.7	14.5	15.0	15.0
1975	11.1	11.1	10.2	9.1	9.3	9.7	11.6	10.5	14.5	14.3	13.2	13.2
1976	11.5	11.5	11.6	11.0	12.5	12.9	12.6	12.8	14.6	14.5	14.9	15.0
1977	15.0	15.0	12.1	12.7	13.2	13.1	13.0	13.5	14.5	15.5	16.0	16.5
1978	18.5	18.5	18.4	15.0	15.2	13.4	13.8	13.8	14.8	16.0	18.0	18.0

Table 2. NEW YORK FRESH APPLE SALES, 1949-1978

Crop Year	Jly	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
						(Million pounds)						
1949	-	10.0	33.2	53.2	56.5	49.9	49.9	39.9	20.0	16.6	3.3	-
1950	-	9.3	31.1	52.8	49.7	46.6	46.6	37.3	18.6	15.5	3.1	-
1951	-	8.5	28.5	48.4	45.6	42.7	42.7	31.3	19.9	14.2	2.8	-
1952	-	7.1	23.7	40.3	37.9	35.6	35.6	26.1	16.6	11.9	2.4	-
1953	-	7.7	25.6	43.5	40.9	38.4	38.4	25.6	17.9	15.4	2.1	-
1954	-	8.4	27.9	47.4	44.6	39.0	41.8	27.9	22.3	16.7	5.1	-
1955	-	10.9	36.4	61.9	58.3	51.0	54.6	32.8	29.1	25.5	5.6	-
1956	-	7.8	26.0	44.3	41.7	36.5	39.1	23.4	20.8	18.2	7.3	-
1957	3.6	10.9	36.4	65.6	54.7	47.4	43.7	29.2	32.8	25.5	5.2	3.6
1958	-	8.7	47.7	73.8	56.4	47.7	56.4	39.1	39.1	34.7	10.9	8.7
1959	-	9.1	50.0	77.3	63.7	50.0	59.1	45.5	45.5	31.8	21.7	4.5
1960	-	12.3	49.3	69.9	53.4	45.2	45.2	41.1	41.1	32.9	18.2	4.1
1961	-	14.9	54.5	84.2	64.4	59.5	54.5	49.6	49.6	34.7	16.4	5.0
1962	-	13.9	46.3	69.4	64.8	55.5	50.9	46.3	46.3	37.0	24.8	4.6
1963	-	10.6	38.7	56.3	45.8	35.2	45.8	31.7	35.2	28.2	27.8	3.5
1964	-	10.6	38.9	53.1	38.9	31.9	38.9	35.4	42.5	31.9	21.1	10.6
1965	-	9.8	32.6	48.8	35.8	35.8	32.6	32.6	39.1	29.3	21.2	9.8
1966	6.5	12.9	29.1	45.2	32.3	32.3	32.3	32.3	38.7	29.1	19.5	9.7
1967	3.8	7.6	34.1	49.3	45.5	41.7	41.7	37.9	41.7	37.9	22.6	11.4
1968	7.0	7.0	31.4	41.8	34.8	31.4	31.3	34.8	38.3	34.8	26.5	27.9
1969	3.5	10.4	31.3	45.2	34.8	34.8	31.3	31.3	34.8	38.3	31.4	24.3
1970	7.1	7.1	28.5	42.7	39.2	35.6	32.0	35.6	42.7	32.0	28.5	24.9
1971	7.1	7.1	21.2	31.9	49.4	38.8	38.8	38.8	35.3	31.9	28.2	24.7
1972	5.8	5.8	20.3	31.9	31.9	26.1	29.0	29.0	34.8	34.9	31.9	11.6
1973	6.0	9.0	24.0	36.0	36.0	27.0	27.0	27.0	33.0	33.0	30.0	12.0
1974	3.0	9.0	21.0	42.0	30.0	27.0	33.0	33.0	30.0	30.0	30.0	9.0
1975	8.1	12.2	44.6	48.6	40.0	41.0	36.5	32.4	36.5	36.5	28.4	28.4
1976	8.9	11.8	26.6	38.4	29.5	23.6	26.6	26.6	26.6	26.6	23.6	20.7
1977	3.6	7.2	39.6	46.8	43.2	36.0	32.4	36.0	36.0	36.0	28.8	14.4
1978	4.3	8.5	34.0	51.0	38.3	42.5	46.8	42.5	46.8	46.8	42.5	21.3

Figure 7. SCATTER DIAGRAMS OF SEASONAL DEMAND for New York State Apples, Monthly Data, 1959 to 1968



3. Other fruits, such as oranges and bananas, also have an impact on demand.

4. Finally, because farm-level prices are deflated by the Consumer Price Index, a marketing margin variable is included as an independent variable [13].

Consumer disposable income, deflated by the Consumer Price Index, was available on a quarterly basis for the United States from the National Bureau of Economic Research. Monthly data were derived by interpolating between quarters. A problem with using an income variable with time-series data is that deflated income shows a steady increase over time. Because of this, income often reflects any other variables associated with time trend rather than the impact of income on the dependent variable by itself.

Discovering the proper variables to use to represent substitutes was extremely difficult because of the disparity between the conceptual variables and the available data. To study substitutes for apples, it is important to determine the geographical market in which New York apples are sold. Although not all New York apples are sold in the state, it would be false to assume that they are sold in a true national market. Therefore, the geographic area in which New York fresh apples are sold should be determined, then the amount of other apples sold in the region should be determined. This measurement in a practical sense is impossible. A number of proxy variables to measure substitutes for apples are available. The Market News Service publishes monthly unloads of apples from various origins in various cities. Also, annual production is available on a national and state basis.

Of the different variables considered as proxies for substitutes, only total annual U.S. production of apples, with New York apple production removed, showed consistent signs and significant t-statistics. Obviously this is theoretically weak since all U.S. apples are not pooled together before sale. However, this variable does account for apples in some way as part of a national market in which, for example, Washington apples are sold in New York and New York apples are sold in Alabama.

The only variable to represent other fruits as substitutes that was tested was the Market News Service unloads of oranges in New York City. This variable either showed incorrect signs when included in the regressions or was clearly insignificant. Theoretically, oranges, bananas, and other fruits should all be substitutes for apples at some price levels. However, it may be that fruits are substitutes only when the price disparities between them are very high.

Including a variable for changes in marketing margins also proved difficult. Two variables were tested and neither provided significant results. The first attempt used the difference between the U.S. average retail price and the U.S. average farm level price. This assumed that the marketing margin for apples is determined by the cost of a bundle of services and not by demand. A second effort was made using the proportional differences between retail and farm price. Both of these variables were also lagged one month with no evidence that the effect of this variable was different from zero.

The availability of controlled-atmosphere storage is assumed to have shifted the demand for apples to the right during the 30-year period. This is an innovation-induced shift because of the availability of higher quality apples later in the season. Two approaches can be used to determine this shift. First, a discrete approach can be used, in which demand equations are estimated for different discrete time periods. Second, a continuous shift can be estimated, in which a variable for controlled-atmosphere storage is included in the estimated equations. This second approach was used. However, the shift was only allowed to occur every year since annual figures for controlled-atmosphere storage were used. The variable used to estimate the shift was the amount of controlled-atmosphere storage facilities used in New York divided by the total New York fresh sales.

The harvest season (August to November) and storage season (December to June) equations are shown below. They were estimated using ordinary least squares with the computer package TROLL using monthly data for the years 1949 through 1978.

Harvest Season

$$P = 7.55 - \underset{(.004)}{.043Q} - \underset{(.016)}{.066CA} + \underset{(.006)}{.034Y} - \underset{(.017)}{.064S} + \underset{(.358)}{1.92D_{73}}$$

Storage Season

$$P = 14.12 - \underset{(.007)}{.059Q} - \underset{(.019)}{.061CA} + \underset{(.007)}{.003Y} - \underset{(.019)}{.136S} + \underset{(.431)}{1.88D_{73}}$$

where:

P = Monthly real New York farm level fresh apple price, cents/pound (deflated by the Consumer Price Index)

Q = Monthly quantity of fresh New York apple sales, million pounds

CA = Annual controlled-atmosphere storage apple holding in New York divided by New York apple production.

Y = Consumer disposable income, \$/month, deflated by the Consumer Price Index (extrapolated from a quarterly series)

S = Annual U.S. apple production less New York production, 100 million lbs.

D_{73} = Dummy variable, observations from March 1972 to September 1974 equal 1, all other observations equal 0.

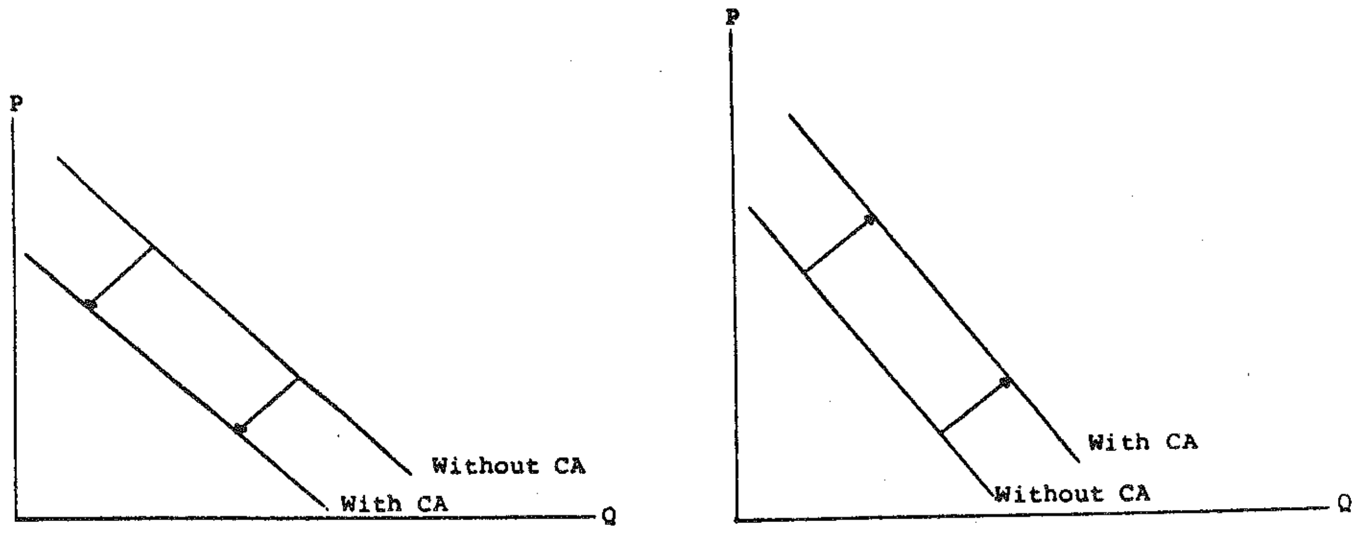
The dummy variable for the spring of 1982 to the fall of 1974 was included after examining the residuals and noting a series of extremely high negative residuals in this period. The period was one of extremely unstable farm prices, attributed to the lifting of wage and price controls and to the Russian grain purchases. The R_2 for the harvest season equation is 0.67, and 0.55 for the storage season equation. A number of residuals other than those for the 1973 time period appear in the data as significant outliers. However, there is no theoretical reason to delete other observations through the use of dummy variables.

The estimated equations offer an interesting suggestion of the role of controlled-atmosphere storage on demand. The shift back of the harvest season demand curve because of controlled-atmosphere storage corresponds with a nearly equal shift to the right in the storage demand curve because of controlled-atmosphere storage. Thus, it would appear that total demand for apples was not affected by controlled atmosphere, but rather demand shifted from harvest season toward storage season and consumption became more equal throughout the year. This hypothesis was tested by running a pooled regression for harvest and storage months combined and including the controlled-atmosphere storage variable. The regression coefficient for the controlled-atmosphere storage variable was not significantly different from zero.

These demand shifts are presented graphically in Figure 8. The coefficients in the demand equations for the controlled-atmosphere storage variable are nearly the same, 0.066 for the harvest season equation and 0.061 for the storage season equation, and cannot be demonstrated to be statistically different. This means that the total annual demand for apples was unchanged by controlled-atmosphere storage.

Nevertheless, this interpretation of the model is difficult since it suggests that controlled-atmosphere storage caused a downward shift in the demand for harvest season apples. The line of causality is clouded because this is an incompletely specified model. Having controlled-atmosphere storage apples available should shift demand to the right for storage apples, and this shift could eventually make demand in the storage season equal to the demand in the harvest season since apples will be of the same quality in both time periods. However, controlled-atmosphere

Figure 8. SEASONAL DEMAND FOR APPLES WITH AND WITHOUT CA STORAGE



A. Harvest Season Demand

B. Storage Season Demand

storage should not necessarily have convinced consumers to buy less in the harvest season. Rather the controlled-atmosphere storage variable, which had a strong upward trend, probably offsets a decline in demand for apples because of other factors not included specifically in the equation. That is to say, controlled-atmosphere storage appears to have caused the outward shift in storage demand, but is associated with a reverse shift in harvest demand.

Without controlled-atmosphere storage, demand for apples during the harvest season would have been the same as with controlled-atmosphere storage present, if it is assumed that the controlled-atmosphere storage variable is a proxy for other factors omitted from the harvest season equation that are the true cause of the backward shift. One possible reason for the results of the equations is a change in consumer preferences over the time period. Consumers have switched from processing fruit at home to purchasing processed fruit from manufacturers. This has reduced overall demand for fresh fruit in the harvest season. The decreased demand for apples for home processing would be most strongly seen in the harvest season because most home processing of apples has traditionally taken place during harvest time.

Another possible reason for the regression results is that apples came under greater competition from other fruits, which also showed increased quality and availability over time. The quantities and prices of selected fruits are presented in Table 3. An upward movement in sales and a downward movement, or level trend, in real price is present for each fruit. More inexpensive citrus and deciduous fruits have become available in the U.S. as competitors to apples during the time period. These other fruits could have provided sufficient competition for apples that, over the 30 years, consumers shifted demand away from apples in both the harvest and storage periods.

Table 3. ANNUAL PRODUCTION AND AVERAGE PRICE FOR SELECTED FRUITS, United States, 1950-1975

Year	Apples		Oranges		Grapefruit		Peaches	
	mil.lbs.	cents	mil.lbs.	cents	mil.lbs.	cents	mil.lbs.	cents
1950	5,228	5.26	10,348	3.16	3,630	1.91	1,554	5.84
1955	4,501	5.79	11,818	3.45	3,562	1.51	2,488	5.66
1960	4,558	5.87	10,544	4.58	3,390	1.84	3,567	4.37
1965	6,135	4.60	12,002	3.09	3,788	2.55	3,448	4.87
1970	6,294	3.86	16,912	2.46	4,944	2.53	3,016	5.37
1975	7,172	4.84	21,434	2.20	5,700	1.63	2,668	6.76

Sources: USDA, _Fruit--Noncitrus Production, Value and Utilization, 1950-1975_, Washington, D.C.; and USDA, Bureau of Agricultural Economics, _Citrus Production_ (Washington, D.C.: Government Printing Office, 1950-1965).

Besides this possibility of specification error, the estimated equations contain other econometric problems. In the storage season equation, the t-statistic for the income variable is low. This is attributed mostly to the upward trend in the controlled-atmosphere storage being colinear with deflated income. The variable for substitutes, total U.S. apple production less New York State production, is a poor proxy for other apple substitutes. However, it did show the best results.

Supply Shifts

Given the estimated demand functions for apples with and without controlled-atmosphere storage, the only other variables needed to compute consumer surplus are the quantities that would have been sold with and without controlled-atmosphere storage. The amount sold with controlled-atmosphere storage is simply the actual quantity sold. What must be estimated is the quantity of apples that would have been sold if controlled-atmosphere storage had not been developed.

A simple approach to this problem is to say that all apples put in controlled-atmosphere storage were an addition to supplies resulting from the new technology. However, by looking at the data this assumption proves false. The quantity of apples stored in New York State for each year from 1949 to 1978 by type of storage (conventional cold storage and controlled-atmosphere storage) is shown in Table 4. The total amount of apples stored has increased whereas cold storage has decreased significantly and controlled-atmosphere storage has increased greatly. This indicates that much of controlled-atmosphere storage has gone to replace conventional cold storage.

Table 4. STORAGE HOLDINGS OF NEW YORK STATE APPLES on November 30, 1949-1978

Year	Total storage holdings	Holdings in CA storage	Holdings in cold storage
		thousand bushels	
1949	6,509	113	6,396
1950	7,850	127	7,723
1951	5,894	206	5,688
1952	4,714	302	4,412
1953	5,167	358	4,809
1954	7,573	475	7,098
1955	7,236	689	6,547
1956	6,021	730	5,291
1957	6,663	1,140	5,523
1958	8,347	1,608	6,739
1959	7,378	1,780	5,598
1960	6,502	1,766	4,736
1961	8,841	2,160	6,681
1962	7,745	2,411	5,334
1963	7,177	2,702	4,475
1964	7,775	3,052	4,723
1965	8,585	3,203	5,382
1966	7,683	2,986	4,697
1967	7,915	3,105	4,810
1968	7,630	3,366	4,264
1969	8,447	3,490	4,959
1970	8,419	3,571	4,848
1971	8,892	3,827	5,065
1972	6,614	3,287	3,327
1973	5,967	3,454	2,513
1974	8,113	3,752	4,361
1975	8,038	4,208	3,830
1976	6,976	3,271	3,705
1977	8,426	4,348	4,078
1978	9,149	4,499	4,650

Source: State of New York Department of Agriculture and Markets, *Cold Storage Holding of Apples in New York*.

To attempt to test the idea that controlled-atmosphere has displaced cold storage, and to measure the amount of displacement, a simple supply regression was run. This regression uses ordinary least squares to estimate the impact of total sales (a proxy for total production) and controlled-atmosphere storage on the amount of apples put in cold storage.

$$\underset{}{CS} = 937.7 + \underset{(.038)}{.365\ TS} - \underset{(.088)}{1.178\ CA}$$

where

CS = Total cold storage holding November 31, 1,000 bu.

TS = Total New York apple production, 1,000 bu.

CA = Total CA storage holding November 31, 1,000 bu.

$R^2 = 0.87$, and

$DW = 2.14$

Annual data from 1959 to 1978.

Total sales (fresh plus processed) was used because some cold storage apples go for processing. The estimated equation suggests that as apple production grows, the amount of apples put in cold storage increases. The equation also suggests that increases in controlled-atmosphere storage decreased the amount of apples put in regular cold storage.

Both of these results were expected, and this regression supports the hypothesis that many controlled-atmosphere stored apples replaced conventionally stored apples. However, the magnitude of the controlled-atmosphere coefficient is bothersome. Since it is greater than 1.00, it suggests that a one-bushel increase in controlled-atmosphere storage decreased cold storage by more than one bushel. This suggests greater than total displacement. Again, this model has the problem of specification error. With controlled-atmosphere storage trending upward over time, the model has picked up the impact of other variables which increased over the same time period. As discussed earlier, one likely cause of a downtrend in cold storage over time could be substitutes.

Knowing that some controlled-atmosphere storage apples displaced cold storage apples, one question remains: how much did controlled-atmosphere storage shift supply to the right? This amount is needed on a monthly basis because the demand estimates used monthly data. A simple approach was used to solve this problem. Monthly controlled-atmosphere and cold storage holdings were available for the years 1955 to 1978 (before 1955 only total controlled-atmosphere storage figures were available). It was assumed that before 1958 all controlled-atmosphere stored apples were a shift to the right in supply, and did not displace cold storage apples. This was assumed because until 1958 less than 20 percent of stored apples were in controlled atmosphere, and because cold storage had stayed at 30 to 40 percent of total production. The percent of total production that was moved from cold storage to later storage period months was computed for the years 1955 to 1957 and averaged for those three years.

These percentages were then applied to years 1958 to 1978. If the amount of apples moved from all storage (both conventional cold and controlled-atmopshere storage) was greater than the 1955-1957 percent, then that extra amount moved was considered a shift in supply during that month. If the amount moved in that month was less than or equal to the 1955-1957 percent, then the shift in supply was estimated to be zero.

The total amount of controlled-atmosphere stored apples moved each month is shown in Table 5. Estimates of the change in quantity of apples sold because of controlled-atmosphere storage, calculated by using this methodology, is presented in Table 6. The monthly figures for 1949 to 1954 in both tables are estimates using the total amount of controlled-atmosphere storage and allocating it proportionately among months. The allocations were based on movements reported by the New York Crop Reporting Service using a 1956 base. Annual totals for apple sales with controlled-atmosphere storage (actual) and apple sales without controlled-atmosphere storage (estimated) are presented in Table 7 and summarized in Figure 9.

Consumer Surplus

With the equations and estimates calculated for supply and demand, the change in consumer surplus resulting from controlled-atmosphere storage in any month in the storage season can be calculated. Figure 10 presents the situation graphically. The actual situation is that demand is D_1, quantity is $\bar{Q}$, and real farm level price is $\bar{P}$. Without controlled-atmosphere storage, the estimated quantity is Q^*. This estimated quantity can be calculated as actual quantity less the amounts presented in Table 6. Since demand would have been lower without controlled-atmosphere storage, the demand curve would have been at D_2 if controlled-atmosphere storage had not been developed. Therefore, the estimated price if controlled-atmopshere storage had not occurred, is P^*. The change in consumer surplus attributable to controlled-atmopshere storage would be the difference between the estimated consumer surpluses with and without controlled-atmosphere storage. In Figure 10 actual consumer surplus with controlled-atmosphere storage is the area $\bar{P}cb$, and the estimated consumer surplus without controlled-atmosphere would be the area $\bar{P}^*da$. Therefore, the change in consumer surplus would be $\bar{P}cb - \bar{P}^*da$.

Table 5. MONTHLY DISAPPEARANCE OF CA STORAGE HOLDINGS
New York, 1949-1978

Year	Dec	Jan	Feb	Mar	Apr	May-July	Total
			thousand bushels				
1949	-	-	-	26	38	49	113
1950	-	-	-	29	43	55	127
1951	-	-	-	57	90	58	206
1952	-	-	-	52	200	50	302
1953	-	-	-	88	150	120	358
1954	-	-	-	95	250	130	475
1955	-	-	-	153	232	304	689
1956	-	7	27	177	300	219	730
1957	8	7	38	281	429	377	1,140
1958	-	-	16	213	484	895	1,608
1959	-	44	218	512	602	404	1,780
1960	19	24	207	511	562	443	1,766
1961	-	-	125	582	653	800	2,160
1962	8	22	166	640	756	819	2,411
1963	22	80	308	745	667	880	2,702
1964	54	91	318	670	775	1,144	3,052
1965	35	30	387	783	842	1,116	3,203
1966	38	103	469	749	744	883	2,986
1967	31	229	470	748	744	883	3,105
1968	43	378	631	813	739	762	3,366
1969	-	392	530	807	767	994	3,490
1970	-	122	591	940	780	1,139	3,571
1971	48	218	507	845	875	1,334	3,827
1972	71	254	552	761	710	929	3,287
1973	154	277	694	707	738	892	3,454
1974	47	358	553	898	839	1,057	3,752
1975	95	157	758	843	927	1,426	4,208
1976	148	186	467	786	800	884	3,271
1977	215	281	1,008	963	804	1,077	4,348
1978	12	310	721	1,041	841	1,574	4,499

Source: State of New York, Department of Agriculture and Markets, Cold Storage Holdings of Apples in New York.

Table 6. ESTIMATED CHANGE IN QUANTITY OF FRESH APPLE
Sales Caused by CA Storage[a]
New York, 1949-1978

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
				thousand	bushels			
1949	-	-	-	1.1	1.6	2.1	-	4.8
1950	-	-	-	1.2	1.8	2.3	-	5.3
1951	-	-	-	2.4	3.8	2.4	-	8.6
1952	-	-	-	2.2	8.4	2.1	-	12.7
1953	-	-	-	3.7	6.3	5.0	-	15.0
1954	-	-	-	4.0	10.5	5.5	-	20.0
1955	-	-	-	6.4	16.7	5.8	-	28.9
1956	-	0.3	1.1	7.4	16.6	5.0	-	30.4
1957	0.3	0.3	1.6	11.8	18.0	10.0	3.6	45.6
1958	-	-	0.7	1.5	19.3	20.7	8.7	50.9
1959	-	-	-	7.3	14.9	7.7	4.0	33.9
1960	-	-	0.3	4.4	11.4	9.4	3.0	28.5
1961	-	-	-	7.8	16.1	24.0	5.0	52.9
1962	-	-	-	0.5	16.2	20.0	4.2	40.9
1963	-	-	-	2.9	18.0	21.0	3.5	45.4
1964	-	-	-	0.5	17.0	21.2	10.6	49.3
1965	-	-	0.5	6.7	29.0	19.5	9.8	65.5
1966	-	-	-	-	8.3	15.2	9.7	33.2
1967	-	-	-	2.6	7.5	10.4	11.4	31.9
1968	-	-	-	9.2	12.9	16.0	15.0	53.1
1969	-	-	4.9	8.8	20.9	21.4	20.0	76.0
1970	-	-	0.6	14.2	9.7	20.0	14.8	59.3
1971	-	-	-	2.5	12.7	21.5	20.0	56.7
1972	-	-	-	-	9.6	17.5	10.0	37.1
1973	-	-	3.8	0.6	13.2	16.8	10.0	44.4
1974	-	-	-	3.6	16.3	23.4	8.0	51.3
1975	-	-	-	-	12.3	23.7	22.0	58.0
1976	-	-	-	5.1	13.6	15.0	10.3	44.0
1977	-	-	12.1	5.6	10.1	20.0	12.6	60.4
1978	-	-	-	2.4	6.4	31.3	21.0	61.1

[a] Million pound units.

Table 7. ESTIMATED APPLE SALES WITH AND WITHOUT CA STORAGE
New York, 1949-1978

	Harvest Season		Storage Season	
Year	Without CA	With CA	Without CA	With CA
	million pounds			
1949	179.6	174.9	152.9	157.6
1950	167.7	162.4	142.9	148.2
1951	150.8	142.1	131.0	139.7
1952	128.2	115.5	109.0	121.7
1953	140.8	125.8	117.7	132.7
1954	156.1	136.1	128.3	148.3
1955	200.3	171.4	167.5	196.4
1956	143.2	112.5	119.8	150.5
1957	193.1	145.2	171.2	219.1
1958	247.4	204.9	186.6	229.1
1959	254.6	207.5	200.1	247.2
1960	226.0	179.3	184.9	231.6
1961	277.7	220.5	218.0	275.2
1962	268.4	204.6	194.4	258.2
1963	200.7	129.2	151.4	222.9
1964	212.4	131.6	141.5	222.3
1965	198.7	113.9	126.0	211.8
1966	197.0	118.0	119.5	198.5
1967	238.8	156.6	136.5	218.7
1968	226.5	137.4	115.0	204.1
1969	222.6	161.6	121.7	214.0
1970	231.3	136.8	117.5	213.0
1971	236.5	135.2	109.6	210.9
1972	194.3	107.3	89.9	176.9
1973	189.0	97.6	105.0	196.4
1974	195.0	95.7	102.0	201.3
1975	251.8	140.5	145.4	256.7
1976	180.1	93.5	106.3	192.9
1977	219.6	104.6	136.8	251.8
1978	289.2	170.2	131.8	250.8

Figure 9. STORAGE SEASON FRESH APPLE SALES WITH AND WITHOUT CA STORAGE New York, Selected Years

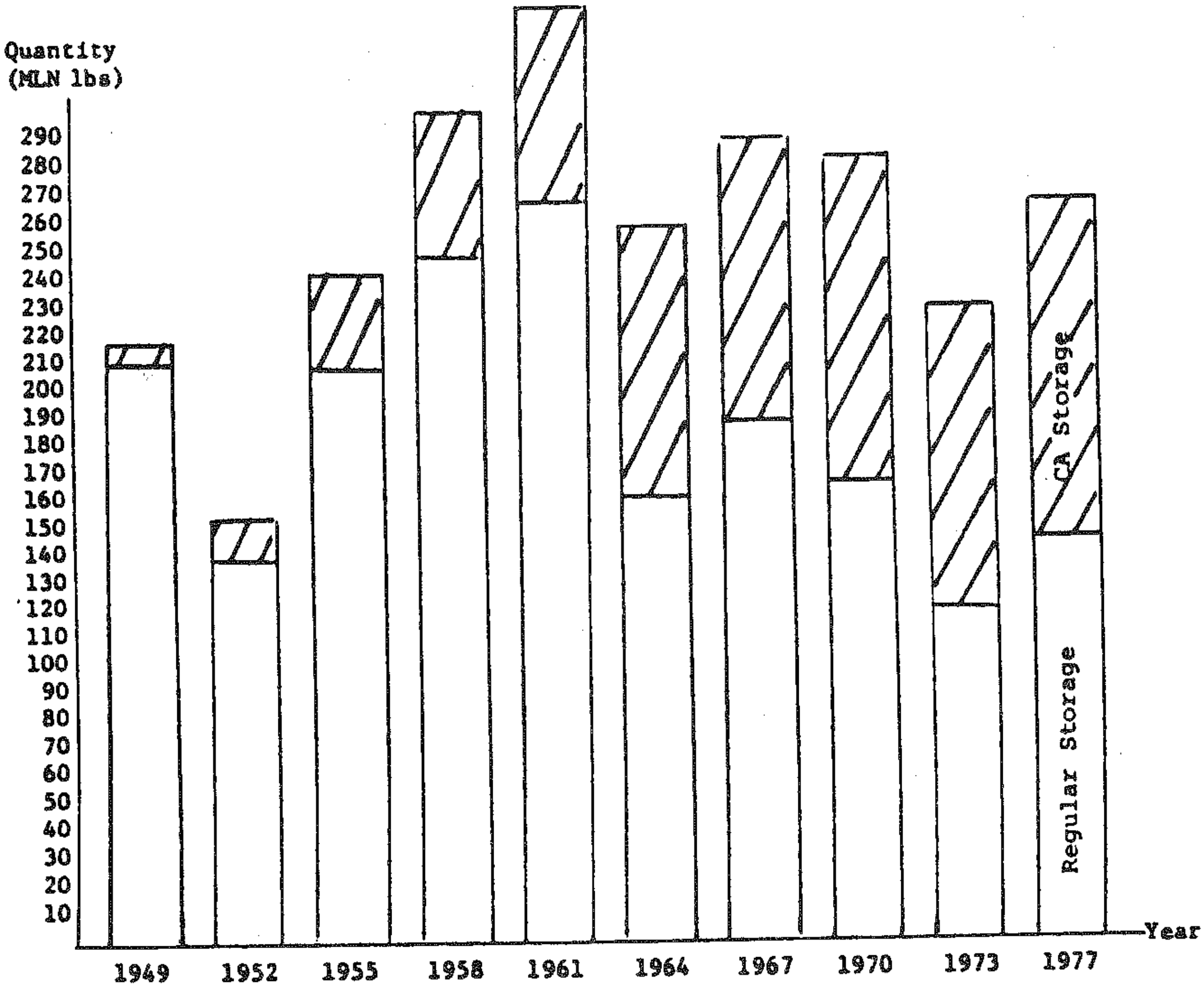
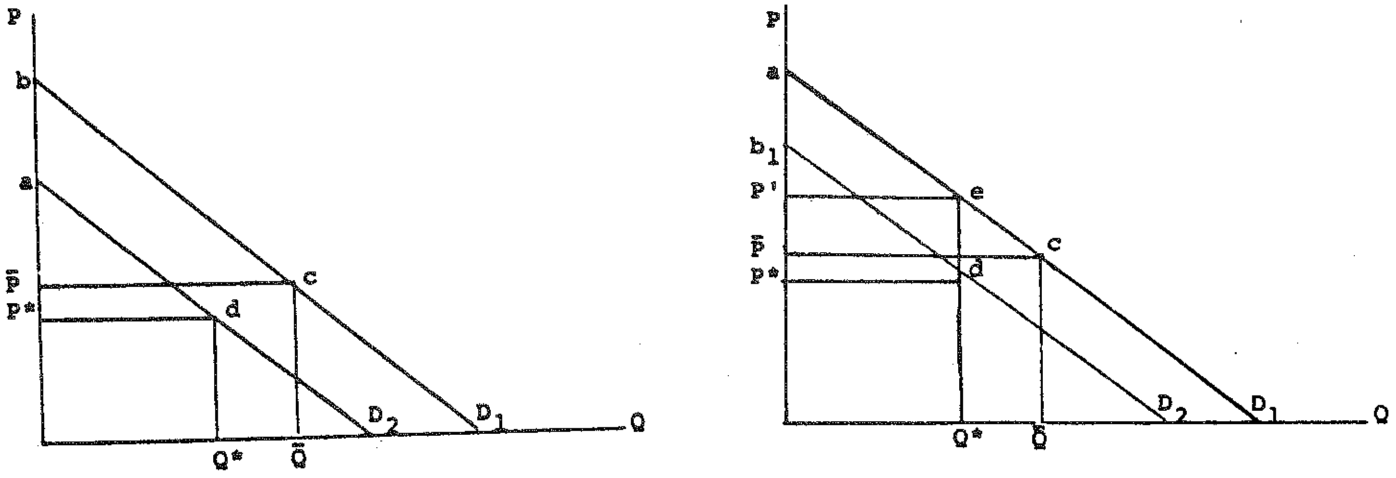


Figure 10. ESTIMATING MONTHLY CHANGES IN CONSUMER Surplus Resulting from CA Storage



With CA Storage

Without CA Storage

For measurement purposes a similar procedure can be followed because the estimated demand functions are parallel. By extending the line Q*d up to the demand line D_1 (see Figure 10), one can see that because D_1 and D_2 are parallel, the triangle aP*d is equal to the triangle bP'e. Therefore, the difference between the consumer surplus with and without controlled-atmosphere storage can be estimated by the area $P'ec\overline{P}$.

To actually calculate this area the needed variables for each month are $\overline{Q}$, $\overline{P}$, Q*, and P'. $\overline{Q}$ and $\overline{P}$ are actual prices and quantities and Q* is actual quantity less the amount of the supply shift calculated. The variable p' can be derived using the estimated demand equations. That is

$$P' = \overline{P} + .059\ (\overline{Q} - Q^*)$$

Given these variables, the change in consumer surplus is

$$CA = Q^*(\overline{P}' - P) + 1/2(\overline{Q} - Q)\ (P' - P)$$

This estimate of consumer surplus, using derived demands, assumes that marketing margins are in absolute terms. That is, in reality, the prices are increased in absolute terms do not affect the prices used in these calculations. The consumer surplus for each storage month in the time period and annual sums is presented in Table 8.

Table 8. STORAGE PERIOD CONSUMER SURPLUS ESTIMATES
New York, 1949-1978

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Total	Possible loss in harvest season
					thousands				
1949	$ -	$ -	$ -	$ 12	$ 15	$ 3	$ -	$ 30	$ 80
1950	-	-	-	13	15	3	-	31	81
1951	-	-	-	26	28	2	-	56	128
1952	-	-	-	20	39	2	-	61	159
1953	-	-	-	35	46	77	-	88	205
1954	-	-	-	48	71	9	-	128	296
1955	-	-	-	98	169	15	-	282	564
1956	-	6	15	75	97	8	-	201	441
1957	8	8	27	187	175	35	4	444	933
1958	-	-	16	34	285	139	22	496	1,158
1959	-	-	-	180	214	65	6	465	794
1960	-	-	7	101	183	65	5	361	608
1961	-	-	-	21	253	181	7	652	1,387
1962	-	-	-	14	276	210	6	500	942
1963	-	-	-	58	204	131	4	397	854
1964	-	-	-	12	235	133	33	413	879
1965	-	-	10	141	253	112	28	545	1,127
1966	-	-	-	-	122	135	28	284	486
1967	-	-	-	62	151	131	38	382	525
1968	-	-	-	164	216	221	180	781	810
1969	-	-	83	158	343	216	169	969	1,305
1970	-	-	12	298	155	218	153	837	936
1971	-	-	-	50	191	221	173	636	843
1972	-	-	-	-	153	239	39	431	434
1973	-	-	56	12	206	214	41	529	607
1974	-	-	-	66	210	253	24	553	702
1975	-	-	-	-	220	231	226	678	1,087
1976	-	-	-	90	159	142	95	486	607
1977	-	-	188	122	184	222	60	776	1,084
1978	-	-	-	65	165	496	134	859	1,069

Finally the complication of an impact of controlled-atmosphere storage on harvest demand needs to be appraised. If the estimated demand curves are accepted, then it must be realized that demand did shift back in the harvest period and a loss in consumer surplus from not selling the apples in the harvest period must be subtracted from consumer surplus in the storage period. This procedure has been followed and the results are reproduced in the final column of Table 8.

If one assumes that demand did shift to the right in the storage period because of controlled-atmosphere storage, but that it did not shift harvest demand back, then the consumer surplus estimates for the storage period in Table 8 can be used without regard to losses. This assumes that farmers would have supplied the same amount of apples in the harvest period with or without controlled-atmosphere storage, but with it they were able to supply more high value apples in the storage period. This seems the more realistic assumption.

Returns to Producers

In addition to consumer surplus, another benefit from agricultural research is the increase in producers' revenue derived from the innovation. In this analysis returns to producers are measured as the amount for which producers sold controlled-atmosphere storage apples minus the amount that they would have received if there were no controlled-atmosphere storage. Subtracting storage costs from the change in revenue yields net benefits to producers. Again, the two assumptions concerning the impact of controlled-atmopshere storage on harvest season demand has an impact. If controlled-atmosphere did shift harvest demand, then the price of the apples sold without controlled-atmosphere would be higher than if it is assumed controlled-atmosphere did not affect harvest demand.

The increase in revenue from controlled-atmosphere storage is simply the total amount of controlled-atmosphere storage apples sold in each month times the average monthly price. The annual sums of the monthly increases in revenue from controlled-atmosphere storage are entered in column 1, Table 9. The value of these apples, if they had not been put into controlled-atmosphere storage, can be broken down into two categories: (1) apples which would have been put in cold storage and still have been sold in the storage season, and (2) apples which would have been sold in the harvest season. The price of the apples which would still have been sold in the storage season, but out of cold storage instead of controlled-atmosphere storage, can be calculated by using the previously estimated equation for storage season demand without controlled-atmosphere storage. To determine the price of the apples which would have been sold in the harvest period if there had been no controlled-atmosphere storage, it is again necessary to make the two assumptions about whether or not controlled-atmosphere shifted harvest season demand back.

Table 9. ESTIMATES OF CHANGES IN PRODUCER REVENUES Caused by CA Storage, New York, 1949-1978

		Revenue Reduction			Net Revenue	
Year	Revenue (1)	Assumption One (2)	Assumption Two (3)	Storage (4)	Assumption One (5)	Assumption Two (6)
			Thousands, (1967 dollars)			
1949	$ 314	$ 225	$ 229	$ 49	$ 40	$ 36
1950	247	314	320	55	(122)	(128)
1951	552	401	419	89	62	44
1952	1,184	939	984	131	114	69
1953	1,338	1,130	1,189	154	54	(5)
1954	1,359	1,330	1,425	206	(177)	(272)
1955	1,881	1,520	1,670	298	63	(87)
1956	2,665	2,260	2,497	316	89	(148)
1957	3,543	2,401	2,813	494	648	(236)
1958	2,798	2,475	2,998	524	(201)	(724)
1959	2,009	1,678	2,046	509	(178)	(546)
1960	2,560	1,692	2,028	472	396	60
1961	4,568	2,524	3,162	693	1,351	713
1962	3,231	2,102	2,692	656	473	(117)
1963	5,170	2,687	3,662	734	1,749	774
1964	5,822	2,688	3,863	815	2,319	1,144
1965	7,625	3,467	5,256	944	3,214	1,425
1966	4,035	1,895	2,746	701	1,439	588
1967	3,735	2,153	2,879	713	879	143
1968	6,621	3,716	5,142	892	2,013	587
1969	6,231	4,596	6,705	1,059	576	(1,533)
1970	5,127	2,846	4,487	964	1,317	(324)
1971	4,815	3,027	4,733	991	797	(909)
1972	5,231	2,450	3,619	777	2,004	835
1973	6,640	4,105	5,523	849	1,686	268
1974	6,707	3,996	5,628	943	1,768	136
1975	5,860	3,278	4,947	1,069	1,513	(156)
1976	5,443	2,843	4,196	818	1,782	429
1977	7,156	4,083	6,105	1,098	1,975	(47)
1978	5,656	4,985	6,782	1,128	(957)	(2,254)

The amount of controlled-atmosphere stored apples which would have been sold in the harvest and in the storage seasons if controlled-atmosphere had not been developed was determined (Table 7). The value of these apples was determined using the estimated demand equations. Without the introduction of controlled-atmosphere storage, the price of the apples in the storage period would be affected by two factors: the quantity of apples sold would be less, which would increase the price; however, controlled-atmosphere apple holdings would be decreased to zero.

Computing the reduction in revenue for the possibility of selling the estimated proportion of the controlled-atmosphere stored apples in the harvest period needs to take into account the same two assumptions discussed earlier. Under the first assumption, that controlled-atmosphere storage itself did not shift the harvest season demand curve, the price of apples can be computed simply. Since the demand equation uses monthly data, the increase in quantity sold during harvest was divided by four and assumed to be equally divided among months. The prices of these monthly sums was estimated as the actual price of the apples less the increase in quantity times 0.043 (the slope coefficient from the harvest equation). The sums of the annual producer revenue losses due to the possibility of selling controlled-atmosphere stored apples in other periods under this first assumption are recorded in column 2 of Table 9.

Under the second assumption, when controlled-atmosphere storage did shift the harvest demand back, the price calculated for the increased harvest season sales must be increased by 0.066 times the annual controlled-atmosphere storage apple holdings in New York. This was done for each relevant harvest month. These prices, using the second assumption, were multiplied by the estimated increases in harvest apple sales and summed across years. The sums of the annual losses in producer revenue due to the possibility of selling controlled-atmosphere stored apples in other periods under this assumption are recorded in column 3 of Table 9.

The other loss in revenue to apple producers is the cost of storage. Costs of storage can be broken into two categories--costs of building the facilities, or fixed costs, and annual operating costs, or variable costs. For this analysis, the fixed building costs are considered investment costs and grouped with the costs of research on the cost side of the benefit-cost estimates. Variable annual operating costs are subtracted from producer revenue and entered in column 4 of Table 9.

The summations in columns 5 and 6 of Table 9 represent estimated changes in producer revenue from the adoption of controlled-atmosphere storage under the two assumptions. Column 6, which represents the change under the assumption that demand did shift back during the harvest period resulting from controlled-atmosphere storage, shows many negative returns. Column 5, under what is probably the more realistic assumption shows mostly positive net returns.

The Benefit-Costs Calculations

Once the benefits of controlled-atmopshere storage research are calculated, all that is left for the benefit-cost calculations is to estimate the costs of research. As explained earlier, fixed costs (building costs) of controlled-atmosphere storage facilities will be considered on the cost side of the analysis, whereas variable costs of operating controlled-atmosphere storage facilities are subtracted from the change in producer revenue. Professor Robert Smock of the Pomology Department at Cornell University supplied the figures on research costs. He estimated expenses at the state experiment station and at Cornell University for controlled-atmosphere storage research from 1937 to 1973. These estimates were terminated in 1973 because it was assumed that research expenditures have at least a five-year lag period before affecting production. Professor Smock's estimates are included in Table 10 in 1967 dollars. All other benefits and costs of controlled-atmopshere storage research estimated in previous sections are also summarized in Tables 10 and 11.

Table 10. ESTIMATES OF COSTS OF CA RESEARCH
New York, 1937-1978

			Costs				
Year	Research costs	Building costs	Total costs	Year	Research costs	Building costs	Total costs
			thousands, 1967 dollars				
1937	3.4	-	3.4	1958	56.8	477	533.8
1938	3.4	-	3.4	1959	56.8	-	56.8
1939	3.4	-	3.4	1960	56.8	854	910.8
1940	3.4	-	3.4	1961	35.2	696	731.2
1941	3.4	-	3.4	1962	35.2	807	842.2
1942	4.7	-	4.7	1963	35.2	971	1,006.2
1943	5.7	-	5.7	1964	16.6	419	435.6
1944	5.7	-	5.7	1965	22.1	-	22.1
1945	5.7	-	5.7	1966	38.8	-	38.8
1946	5.7	-	5.7	1967	17.1	451	468.1
1947	22.7	-	22.7	1968	22.5	344	366.5
1948	22.7	314	336.7	1969	5.0	225	230.0
1949	22.7	39	61.7	1970	5.4	710	715.4
1950	22.7	219	241.7	1971	6.1	-	6.1
1951	22.7	267	289.7	1972	9.2	-	9.2
1952	22.7	157	179.7	1973	8.2	-	8.2
1953	56.8	324	380.8	1974	-	1,056	1,056.0
1954	56.8	593	649.8	1975	-	-	-
1955	56.8	113	169.8	1976	-	388	388.0
1956	56.8	1,137	1,193.8	1977	-	419	419.0
1957	56.8	1,297	1,353.8	1978	-	-	-

Table 11. ESTIMATES OF BENEFITS OF CA RESEARCH
New York, 1949-1978

	Benefits					
	Assumption 1			Assumption 2		
Year	Total benefits	Consumer surplus	Producer surplus	Total benefits	Consumer surplus	Producer surplus
	thousands, 1967 dollars					
1949	70	30	40	(14)	(50)	36
1950	(91)	31	122	(178)	(50)	(128)
1951	118	56	62	(28)	(72)	44
1952	175	61	114	(29)	(98)	69
1953	142	88	54	(122)	(117)	(5)
1954	(49)	128	(177)	(440)	(168)	(272)
1955	345	282	63	(369)	(282)	(87)
1956	290	201	89	(388)	(240)	(148)
1957	1,092	444	648	(253)	(489)	236
1958	295	496	(201)	(1,386)	(662)	(724)
1959	287	465	(178)	(875)	(329)	(546)
1960	757	361	396	(187)	(247)	60
1961	2,003	652	1,351	(22)	(735)	713
1962	973	500	473	(559)	(442)	(117)
1963	2,146	397	1,749	317	(457)	774
1964	2,732	413	2,319	678	(466)	1,144
1965	3,759	545	3,214	843	(582)	1,425
1966	1,723	284	1,439	386	(202)	588
1967	1,261	382	879	-	(143)	143
1968	2,794	781	2,013	558	(29)	587
1969	1,545	969	576	(1,869)	(336)	(1,533)
1970	2,154	837	1,317	(423)	(99)	(324)
1971	1,433	636	797	(1,116)	(207)	(909)
1972	2,435	431	2,004	832	(3)	835
1973	2,215	529	1,686	190	(78)	268
1974	2,321	553	1,768	(13)	(149)	136
1975	2,191	678	1,513	(565)	(409)	(156)
1976	2,268	486	1,782	308	(121)	429
1977	2,751	776	1,975	(355)	(308)	(47)
1978	402	859	(457)	(2,464)	(210)	(2,254)

After making estimates of benefits and costs for controlled-atmosphere storage research under assumption one, a number of additional calculations were completed. Determining the appropriate discount rate for such a project is difficult because of the long time frame. Because of this, net present values of all benefits and costs for the project were calculated for an array of discount rates:

Discount rate %	Total benefits (1967 Dollars)	Total costs (1967 Dollars)	Net benefits (1967 Dollars)	Net benefits (1981 Dollars)
		(thousands dollars)		
5	34,884	29,923	4,961	13,494
10	80,514	78,905	1,609	4,377
15	211,576	211,530	46	126

The internal rate of return (discount rate where net present value is zero) is approximately 15.93 percent. This is a high rate, especially when considering that these estimates are discounted and therefore inflation-free. An inflation-free discount rate for public projects during this time period is probably best estimated at five percent. This would allow for the project to have yielded $4,961,030 in net benefits in 1967 dollars, which is equivalent to $13,494,000 1981 dollars.

The above analysis yields a benefit-cost ratio (net present value of total benefits divided by net present value of total costs) of approximately 1.2 given the five percent discount rate. This low ratio occurs with storage construction costs on the cost side of the ratio because they were considered investments in the new technology. The alternative is to consider storage construction costs as negative benefits and subtract them from total benefits. Calculations of total benefits and total costs with storage costs subtracted from total benefits are presented below:

Discount rate %	Total benefits (1967 Dollars)	Total costs (1967 Dollars)	Net benefits (1967 Dollars)
		(thousands dollars)	
5	7,561	2,600	4,961
10	9,731	8,122	1,609
15	26,965	28,919	46

This analysis, which shows the ratio of benefits to research costs, yields a benefit-costs ratio of 2.9 given the five percent discount rate.

Using the five percent discount rate, a net present value of controlled-atmosphere storage to producers was calculated to be $3,603,660 (1967 dollars), when estimated separately by comparing producer surplus to building costs. This assumes that the producers' share of the research cost was minimal and was therefore ignored. This estimate leaves $1,357,370 (1967 dollars) for return to consumers, or a ratio of return to producers returns to consumers of 2.65--quite a bias toward producers.

These calculations, when considered in a qualitative sense, appear to understate consumer benefits relative to producers. In the final analysis higher quality apples are now available from February through July than were formerly available throughout the United States. Pioneering research in New York was quickly adapted after farmer experimentation in New York throughout the United States commercial producing areas. The consumer benefits of innovation in New York were national and worldwide in richer countries where controlled-atmosphere storage became available. In this sense the calculated consumer surplus based on New York data alone is a very conservative statement of the true, but unmeasured benefit stream.

Results and Implications

This analysis began with the hypothesis that returns to research on controlled-atmosphere storage in New York State have been high. Under the most realistic assumptions, net returns to controlled-atmosphere storage research totaled $13,494,000 in 1981 dollars over and above a five percent return on capital expenses after inflation. This represents a high rate of return when compared to the costs of research. For instance, the New York State Agricultural Experiment Station's budget for all research on deciduous fruit in 1974 was $2,289,000. The net benefit to controlled-atmosphere storage research in 1974 dollars is $7,327,441. The returns to controlled-atmosphere storage research alone could cover over three years of the total New York State Experiment Station's deciduous fruit research even under the conservative assumptions followed.

One cannot assume that all, or most, research projects are as successful and produce the returns that controlled-atmosphere storage have provided. To the contrary, for every project such as controlled-atmosphere storage, there are many failures and partial successes. What is significant is that a successful project can produce enough benefits to cover the expenses of many less successful research efforts.

The distribution of benefits often raise some questions about the funding of research. In this analysis, the ratio of returns to producers over returns to consumers was 2.65 in favor of producers. Since funds for agricultural research come from taxes, most of the funds come from consumers. Thus, it would seem the apple producers received an unfair subsidy. However, the risk taken by producers should be compared to the risks taken by consumers. Consumers also take a small risk with the small amount of money paid in taxes for agricultural research. However, producers that experimented with controlled-atmosphere storage invested a large amount of their resources in storage facilities. This analysis discounted net benefits with a five percent interest rate for both producers and consumers. However, considering that producers took greater risks than consumers, perhaps a higher discount rate should have been used for producers' net benefits than for consumers' net benefits. This would have reduced the returns to producers in relation to the returns to consumers.

Benefits from controlled-atmosphere storage did not start to consistently exceed costs until 1959, 22 years after the first expenditures on controlled-atmosphere storage occurred in New York. However, after 1959, benefits greatly exceeded costs. It is this time lapse between research investment and payoff that requires the public sector to undertake a great deal of research with a net benefit to consumers. One assumes that benefits will exceed costs for years to come, and, therefore, increase the returns to controlled-atmopshere storage research both in terms of money and intrinsic enjoyments from eating high quality fresh fruit.

Assumptions and Other Difficulties

The most important assumptions in the analysis concerned the shifts in the demand curves that resulted from controlled-atmosphere storage. Benefit-cost calculations showed high rates of return to controlled-atmosphere storage research if one assumed that harvest demand did not shift back because of controlled-atmosphere storage. However, benefit-cost calculations showed low, even negative rates of return if one assumed that harvest demand did shift back because of controlled-atmosphere storage.

One approach to this problem would be

1. to consider the negative returns, related to the assumption the controlled-atmopshere storage did shift harvest demand back, as a low end of possible returns to the research; and

2. to consider the positive returns, related to the assumption that controlled-atmosphere storage did not shift to consider the positive returns, related to the assumption that controlled-atmosphere storage did not shift harvest demand back, as a high end of possible returns to the research.

However, that approach would be the wrong interpretation of the argument that the demand equations were misspecified because of omitted variables. If key variables were omitted from the equation, which they were, demand in both the harvest and storage seasons would have been shifted back because of those variables. Furthermore, if the controlled-atmosphere storage variable picked up the influence of these other variables, then the shift back in the harvest period shown to be caused by controlled-atmosphere storage did not occur and the shift out in storage season demand was actually much larger than shown in this analysis. Therefore, if this scenario were followed, returns to controlled-atmosphere storage would actually be much greater than shown. The extreme cases, then, would be higher returns if the above scenario were followed, and the low returns, as shown under the assumption that controlled-atmosphere storage did shift harvest demand back. The benefit-cost calculations shown earlier in the analysis represent the middle ground.

Omitting variables for substitutes was not the only problem with the estimated demand equations. Another variable which should have been included was a marketing margin variable. Substitutes for New York apples were represented by total U.S. annual apple production. A dummy variable was needed to remove certain data from the equation. Consumers' income, although specified correctly, was not very important in the regression estimates. All these problems raise questions about the demand related estimates for the benefit-cost calculations.

Lack of appropriate data is associated with many of the problems in estimating the demand equations and the subsequent benefit-cost analysis. Despite having historic data on prices and sales, it was difficult to find the correct series to represent the concepts necessary throughout the analysis. Furthermore, over a 30-year period, the consistency of the data can vary. In the early 1970s, the USDA changed the definition of the weight of a bushel of apples probably because the size of the average apple had increased.

Another data-related problem was the approach used to estimate the shift in supply of apples that resulted from controlled-atmosphere storage. The statistical regression approach proved unsatisfactory and forced the use of a more simplistic approach using the supply of apples before the introduction of controlled-atmosphere storage to estimate the supply of apples after controlled-atmosphere storage. Any analysis which uses a before-after approach is weak because factors change over time. This is the reason that in this analysis a with-without approach was used whenever possible. Ideally, both supply and demand shifts could havebeen estimated using a simultaneous-equations system. However, appropriate data were not available over the time period under study.

Extensions of the Analysis

This analysis focused on the benefits and costs of controlled-atmosphere storage to fresh apple production in New York State. A broader analysis could look at the benefits and costs on a national scale. Other apple-producing states benefited greatly from controlled-atmopshere storage. Producers and consumers in Washington were able to use controlled-atmosphere storage without the large investments in research made in New York. One may argue that early adopters of new technologies receive most of the benefits. Net benefits, however, did not become positive in New York until 1959. By that time the technology had been introduced into other regions. These spillover effects would add to the net benefits of the research. The research funds spent in New York on controlled-atmosphere storage allowed other states' research institutions to develop other new technologies and expanded on initial innovations.

The use of controlled-atmosphere storage has not been limited to apples. Many other fruits and vegetables, such as strawberries and lettuce, are now stored in controlled-atmosphere facilities. Research can adapt controlled-atmosphere storage to other fruits and vegetables. Different temperatures and atmosphere requirements are necessary for different types of produce put in controlled-atmosphere. However, the basic principles developed for apples can be applied in a range of circumstances. This greatly shortens the amount of time required to bring positive net benefits to the research on storing other fruits and vegetables. For apples, it was 22 years before the research began to create net benefits. For strawberries, it might only have taken five years. The development of controlled-atmosphere storage in New York has greatly increased the returns to research in other areas. Although difficult to measure, this is a very real benefit to the research performed by Robert Smock and his associates.

This analysis measured benefits and costs to only producers and consumers. Another group which benefited from the research is fresh-apple marketers. These people, from the wholesaler to the retailer, were able to market an essentially new product in early summer months and increase their profits by taking a marketing margin on controlled-atmosphere stored apples.

Controlled-atmosphere storage has had an impact on the apple processing industry as well as on fresh-apple production. This analysis looked only at the impact of controlled-atmosphere storage on fresh production. However, some apples placed in controlled-atmosphere storage facilities did go to the processing industry. Furthermore, since most fresh apples were put in controlled-atmosphere storage, conventional cold-storage facilities became available for use by processors. This enhances the processing industry because a processor can keep his plant running for a longer period of time by using stored apples and allows higher quality apples for processing.

In conclusion, although this analysis did not completely and accurately measure the complete flow of benefits and costs to controlled-atmosphere storage research, it did show how to use economic tools to develop such a measure. Many assumptions were made which narrowed the scope of the analysis. The true net benefits of the application of controlled-atmosphere storage are most likely much higher than those estimated by the calculations used in this conservative analysis.

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