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Optimal Reserve and Export Policies for the California Almond Industry: Theory, Econometrics and Simulations

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CONTENTS

CONTENTS i

LIST OF FIGURES v

LIST OF TABLES vii

1 INTRODUCTION 1

2 CALIFORNIA ALMOND YIELDS 5
2.1 Introduction 5
2.2 Facts and Notions About Yields 6
Technological Change 6
Vintage Capital—Yields and the Age Distribution 6
Alternate Bearing 7
Weather 8
2.3 Forms for Yield Models 8
The Production Function 8
Age Distribution Effects 9
Alternate-Bearing Effects 9
Interpretation of Coefficients 10
2.4 Data for the Analysis 10
Almond Acreage Data 10
Production and Yield 11
Weather 11
2.5 Estimation of the Yield Model 11
2.6 Forecasting Average Almond Yields 12

3 CALIFORNIA ALMOND ACREAGE RESPONSE 15
3.1 Introduction 15
3.2 A General View of Supply Response 16
Determinants of Long-Run Supply Elasticity 16
Conceptual and Measurement Issues for Supply Response Models 18
Synopsis 19
3.3 Analysis of Supply Response for Perennial Crops 19
3.4 Modeling California Almond Supply Response 22
Yield Models 22
Models of Plantings 22
Models of Removals 23
3.5 Data for the Analysis 24
Almond Acreage Data 24
Production and Yield 25
Almond Prices and Average Revenues per Acre 25
Establishment and Production Costs 25
Revenues 26
After-Tax Net Present Values 28
3.6 Estimation of Models 29
Plantings Model—Traditional 29
Plantings Model—ENPV 30
Removals Model—Traditional 30
Removals Model—ENPV 31
3.7 Validation of Models 31

4 SPANISH ALMOND PRODUCTION 35
4.1 Introduction 35
4.2 Spanish Almond Acreage Response 37
Yield Model 37
Net Investment Models 39
4.3 Forecasting Yields 42
4.4 Conclusion 42

5 THE DEMAND FOR ALMONDS IN NATIONAL MARKETS 43
5.1 Introduction 43
5.2 Theoretical Considerations in Analyzing Almond Demand 45
Consumer Demand 45
Derived Demand 46
Residual Demand 48
Time Framework of Demand Analysis 49
Equilibrium and Rest-of-World Demand 50
The Estimated Structure 50
5.3 Statistical Considerations in Estimating Almond Demand 52
Single Equations vs. Demand Systems 52
Demand for Consumption vs. Demand for Storage 53
General Form of Almond Demand Equations 53
5.4 Data for the Analysis 54
U.S. Almond Statistics 54
Trade Statistics 55
Macroeconomic Statistics 57
5.5 Estimation Results 57
Functional Form 57
Treatment of Abnormal Data 57
Demand Estimates: Large Countries and Rest-of-World 58
Demand Estimates: Uncommitted Inventories 61
The Integration of the World Almond Market: Evidence from Prices 63
5.6 Notes on the Econometric Specification 64
Demand Estimates: Medium-Sized Countries 65
Exogeneity of Prices 67
Model Validation 68

6 A SIMULATION AND FORECASTING MODEL OF THE ALMOND INDUSTRY 71
6.1 Introduction 71
6.2 Determination of Prices and Quantities 71
The Linearized Demand Equations 71
Price Rules 74
Solution with Known Yield, Acreage, and Spanish Net Exports 75
6.3 Plantings and Removals: the Long-Run Model 76
The Plantings and Removals Equations 76
The Evolution of the Age Structure of California Orchards 77
6.4 Within-Sample Simulation Exercises 78
Price-and-Quantity Simulation with Actual Acreage 78
Full Simulation: Acreage, Quantities, and Price Endogenous 79

7 RESERVE POLICY ANALYSIS **81**
7.1 Introduction 81
7.2 Reserve Policy I: No Reserve vs. a Static Profit-Maximizing Reserve 82
7.3 Reserve Policy II: Optimal Reserve Strategies 84
Fundamentals of Cartel Power 85
Dynamic Entry Deterrence 86
The Dynamic Optimization Model 88
7.4 The Empirical Programming Model 89
Construction of the Programming Model 90
Results 92
Analysis of Alternative Reserve Strategies 94
7.5 Summary of Reserve Policy Alternatives 95
7.6 Conclusion 97

8 SUMMARY AND CONCLUSIONS **99**

A CO-INTEGRATION AND UNIT-ROOT TESTS OF THE LAW OF ONE PRICE **101**

B ENTRANT AND INCUMBENT SUPPLY RESPONSE **107**

C DATA TABLES **111**

REFERENCES **127**

LIST OF FIGURES

1.1 Almond Purchases by Major Consuming Countries 2
2.1 California Almond Production 5
2.2 California Almond Yield per Bearing Acre 6
2.3 California Almond Yields, Actual and Predicted 12
3.1 Total, Bearing, and Non-bearing Acreage of California Almonds . . 15
3.2 Plantings of California Almond Acreage, Actual and Predicted . . . 32
3.3 Removals of California Almond Acreage, Actual and Predicted . . . 32
4.1 Total, Bearing, and Nonbearing Spanish Almond Acreage 35
4.2 Spanish Production of Almonds 36
4.3 Yields of Spanish Almonds, Dry-land, Irrigated, and Overall 37
4.4 Actual and Predicted Changes in Total Spanish Almond Acreage . . 41
5.1 Schematic Diagram of California Almond Industry 47
5.2 World Almond Supplies by Producing Countries 48
5.3 Residual Demand for California Almonds 49
5.4 Actual and Fitted Values for Demand Regressions 60
6.1 Flowchart for the Simulation Model 72
6.2 Linearizing the Constant-Elasticity Estimated Demand 73
6.3 Real U.S. Farmgate Price, Actual and Simulated (with actual plantings) 78
6.4 Real U.S. Farmgate Price, Actual and Full Simulation 79
7.1 The Reserve-Policy Optimization Model 91

LIST OF TABLES

3.1 Summary of Main Perennial Crop Supply Response Studies in the Literature . . . 21
3.2 Validation Statistics for Plantings and Removals Models . . . 33
4.1 Regression Models of Spanish Almond Yields . . . 38
5.1 Outliers in Simple OLS Demand Regressions . . . 58
5.2 Almond Demand Regression Results . . . 59
5.3 Correlations among Average Annual Export Prices, 1961–89 . . . 64
5.4 Correlations among Annual Average Import Prices, 1961–89 . . . 65
5.5 Almond Demand in Medium-Sized Countries, Regression Results . . 66
5.6 Hausman Test Statistics comparing OLS and 2-SLS Estimators, for Exogenous Almond Price . . . 69
5.7 Within-Sample and Out-of-Sample Validation Statistics for Demand Equations . . . 70
6.1 Linearized Demand Coefficients . . . 74
6.2 Average Real Markup of Import Prices over U.S. Farmgate Price, in 1985 Dollars per Pound (Kernel Weight) . . . 76
6.3 Validation Statistics for Full Simulation Model . . . 80
7.1 Simulated Almond Price, Plantings, Removals and Bearing Acreage: No Reserve Policy . . . 83
7.2 Simulated Almond Prices, Plantings, Removals and Bearing Acreage: Static Profit-Maximizing Reserve Policy . . . 85
7.3 Optimal 50-Year Reserve Strategies for Alternative Demand Growth Rates . . . 92
7.4 Optimal Reserve Policy Analysis: Base Model with One Percent Demand Growth . . . 93
7.5 Optimal Reserve Policy Analysis: No Price Discrimination . . . 95
7.6 Optimal Reserve Policy Analysis: No Price Diversion to Secondary Markets . . . 96
7.7 Comparison of Alternative Reserve Strategies . . . 96
A.1 Unit-Root Tests on Individual Price Series, 1962–89 . . . 102
A.2 Regression Coefficients and R^2 Statistics from Price Co-integrating Equations, 1962–89 . . . 103
A.3 Test Statistics for Cointegration among Export Prices and the U.S. Farm Price, 1962–89 . . . 104
A.4 Test Statistics for Cointegration among Import Prices, 1962–89 . . . 105
A.5 Test Statistics for Cointegration between U.S. Prices and Selected Import Prices, 1962–89 . . . 105
C2.1: California Almond Acreage by Category, Production, Yield, Rainfall, 1950–92 . . . 112
C3.1: Plantings, Removals, and Expected Net Present Value of California Almond Acreage, 1961–90 . . . 113
C3.2: Prices, Costs and Investment Parameters for California Almonds, 1951–1990 . . . 114
C3.3: Expected Mature Yields and Establishment Costs for California Almond Acreage, 1961–90, and Olson's Yield Factor for Almonds . . 115
C4.1: Spanish Almond Yields and Weather in Almond-Producing Regions of Spain, 1959–89 . . . 116
C4.2: Spanish Almond Acreage, Plantings, Harvests, and Prices; Spanish Agricultural Costs, 1965–89 . . . 117
C5.1: Harvests, Stocks, Domestic Usage, Net Exports, and Prices of California Almonds, and Net Exports of Spanish Almonds, 1961–91 . . . 118
C5.2: Almond Usage and Prices, and Filbert Prices, for Germany, France and Great Britain, and Rest-of-World Almond Usage, 1970–91 . . . 119

C5.3: Almond Usage and Prices, and Filbert Prices, for Japan, the Netherlands and Canada, 1961–91 120
C5.4: Imports, Exports, Harvests, and Prices of Almonds for Italy, 1961–91 121
C5.5: Real Per-Capita Private Domestic Consumption Expenditures, for the United States, Germany, France, the Netherlands, Great Britain, Italy and Japan, and Total Private Domestic Consumption Expenditures for Canada, 1961–91 122
C5.6: Consumer Prices in the United States, Germany France, the Netherlands, Great Britain, Italy, Japan, and Canada, 1961–91 123
C5.7: Real Exchange Rates for Germany, France, the Netherlands, Great Britain, Italy, Japan, and Canada, 1961–91 124
C5.8: Population of the United States, Germany France, the Netherlands, Great Britain, Italy, and Japan, 1961–91 125

1. INTRODUCTION

This study analyzes economic relationships in the California almond industry, including supply relationships for California almonds, demand for California almonds, and supply relationships for Spain, the key foreign competitor to the California almond industry. This information is used to simulate industry behavior under alternative marketing policies that can be implemented under the industry's Almond Marketing Order.

The results from this study are potentially important to the California almond industry and to the state's agricultural economy in general. Almonds are an important agricultural crop in California, and the state is the world's dominant supplier of almonds, annually producing from half to three-fourths of the world's supply. The 1993 crop consisted of 470 million pounds with a farm value of about 900 million dollars, making almonds California's most important tree crop and its ninth most important agricultural product overall. If an improved understanding of the economic relationships in this industry can help guide policy to enhance industry efficiency and profitability, the industry participants will benefit directly and, through multiplier effects, so will other sectors of the California economy.

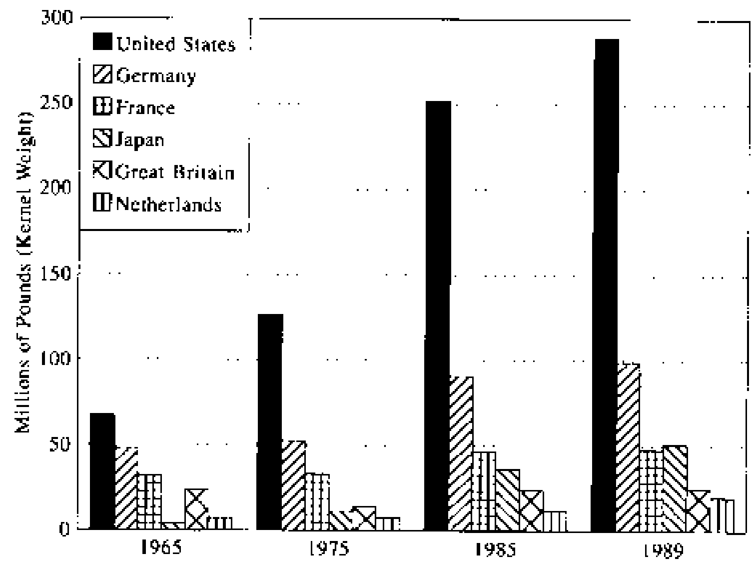
California almonds are marketed under the auspices of a federal marketing order initiated in 1950, and subsequently revised several times. The marketing order authorizes the industry (with the approval of the Secretary of Agriculture) to regulate the flow of almonds to the market through implementation of a reserve policy. Understanding the supply-demand relationships in the industry is crucial to conducting an optimal reserve policy. Providing such information and analyzing alternative marketing strategies are fundamental purposes of the present study.

The next two chapters of the report analyze almond supply in California. Chapter 2 analyzes the determinants of year-to-year fluctuations in almond yields. Understanding the determinants of yield is crucial to developing crop forecasts which, in turn, are key inputs to developing reserve strategies. The work in Chapter 2 extends previous analyses of almond yield by demonstrating the importance of the age distribution of trees and developing an improved analysis of almonds' alternate bearing cycle. The model also quantifies a strong negative correlation between yields and rainfall during the February bloom period.

Chapter 3 focuses on short- to medium-run acreage response in the industry. The chapter advances the proposition that, over the long run, supply in the industry will be very responsive to changes in price and profitability, implying that policies to increase prices and profits will eventually be offset by expansion of acreage in almonds. However, the time to full adjustment in a perennial crop industry such as almonds may be rather long, suggesting that the magnitudes of short- to medium-run supply adjustments both domestically and overseas are the key factors determining the success of programs designed to raise prices through supply restriction or demand expansion.

Chapter 3 provides a conceptual development and statistical estimation of economic models to predict both plantings and removals of almond acreage in California. The results document a positive relationship between plantings and expected revenues and an inverse relationship between planting and variable production costs. As expected, these relationships are reversed when removals are considered. These models enable the analyst, armed with revenue projections from a possible industry policy, to quantify the nature of supply response to price changes and thus to project the long-run effects of policies to expand demand or restrict supply.

Our analysis of almond demand indicates that the main substitute for California almonds is almonds grown elsewhere in the world, which today essentially means almonds grown in Spain. Thus, our analysis of competitor supply response in Chapter 4 is focused on the Spanish almond industry. Yield and acreage response models similar to those estimated for the California industry in Chapters 2 and 3 are esti-



U.S.: Harvests plus carryin less carryout less net exports
Other countries: Net imports

Figure 1.1: Almond Purchases by Major Consuming Countries

mated for the Spanish industry. Spain has the potential to "free ride" on policies undertaken by the California industry aiming to expand demand or restrict supply. Thus, how Spain responds to these market forces is important to the success or failure of such policies.

Chapter 5 discusses the important demand concepts that apply to the almond industry. Chapter 6 presents the results from analyses of demand for almonds in key almond-consuming countries. The specific countries studied are the United States, Japan and the European Community (EC) countries of France, Germany, Italy, The Netherlands, and The United Kingdom. The major almond consuming countries and their relative importance are depicted in Figure 1.1. A key conclusion emerging from these country-level analyses of demand is that demand is inelastic (relatively unresponsive to price changes) in most countries, with the United States appearing to be an exception. This conclusion has important implications for reserve policy that are explored in Chapters 6 and 7.

Another important conclusion from the demand analysis is that substitution relationships between almonds and other nuts are rather weak. Filberts appear to be a modestly important substitute in Germany but are rather unimportant elsewhere.

Chapters 6 and 7 discuss integration of the supply and demand analyses to generate simulation and optimization models of the almond industry that are then used to study behavior under alternative marketing order strategies. Chapter 6 describes a flexible simulation model that can project almond industry response to a wide range of market shocks. Validation of this model is also discussed in Chapter 6 as is use of the model for short-term forecasting of production and price.

Chapter 7 is devoted to analysis of supply control strategies under the Almond Marketing Order. Use of the simulation model to analyze industry outcomes under alternative marketing strategies revealed an important tradeoff from implementation of policies to maximize year-to-year profits to the California almond industry. Policies that raise profits in the short run stimulate expanded almond acreage, causing increased production and reduced profits in the long run unless progressively more stringent supply controls are applied. Chapter 7, thus, describes construction and analysis of an optimization model which, given the industry structure developed in Chapters 3–5, solves for the trajectory of supply management strategies that maximizes discounted profits to the California almond industry over a 50-year horizon. Various restrictive strategies are developed and compared with the overall optimal strategy.

2. CALIFORNIA ALMOND YIELDS

2.1 Introduction

Total production of almonds during a given year is a function of total bearing acreage and average yields. This chapter presents a model of California almond yields that can be used to predict production from a given bearing acreage. Chapter 3 deals with the longer-run acreage response that includes adjustments in bearing acreage resulting from plantings and removals.

In the post-war period, total U.S. almond production grew from 56,600 pounds (kernel weight) in 1946 to 656,200 pounds in 1990, an increase by a factor of over 11 in just 45 years. Figure 2.1 shows the time path of total production. The tremendous growth in production is due to increases in both bearing acreage and average yields. During the post-war period bearing acreage increased by a factor of four, from about 90,500 acres in 1950, to 168,500 acres in 1970, and 356,800 acres in 1992. During the same period, average yield per acre tripled, from about 500 pounds per acre (kernel weight) in 1950 to 1,540 pounds per acre in 1992 (both years are "high" years in the alternate-bearing cycle).

The dramatic growth in average almond yields is illustrated in Figure 2.2. Yield is affected in a secular way by changes in technology and changes in cultural practices, in a cyclical fashion due to alternate bearing patterns, and by random variations in weather, pest problems, and so on. In addition, because yields vary as trees mature (and eventually depreciate), average yield depends systematically on changes in the age structure of the population of trees which, in turn, depends on the past pattern of investments in new plantings and removals of orchards. In this chapter we will develop models of average yields of bearing almonds that incorporate variables to capture these effects over time.

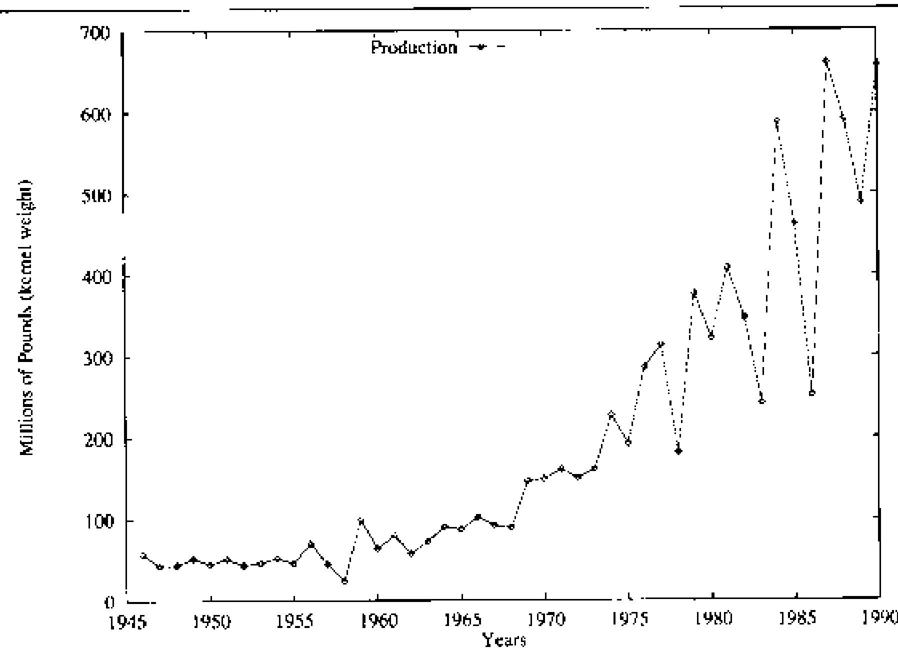


Figure 2.1: California Almond Production

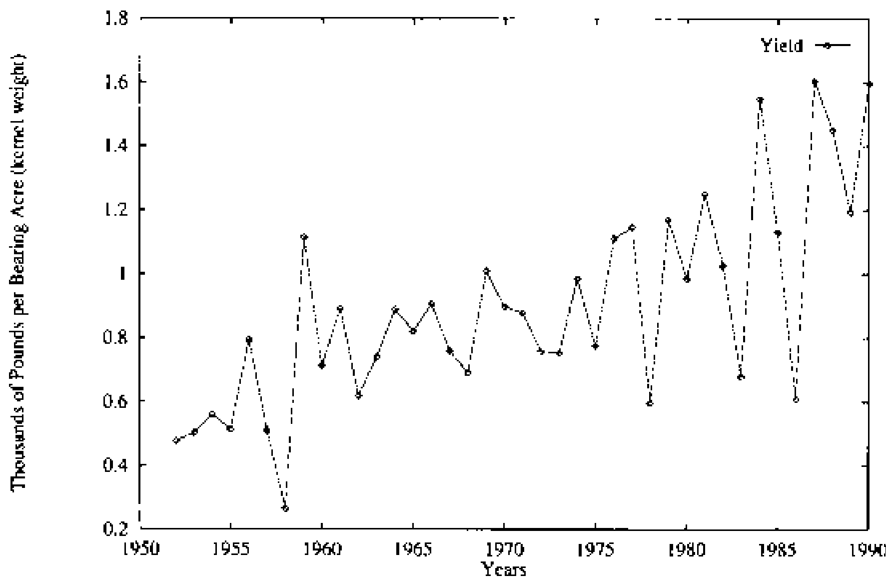


Figure 2.2: California Almond Yield per Bearing Acre

2.2 Facts and Notions About Yields

Technological Change

The California almond industry has adopted a number of new technologies over time. These include mechanical harvesting, improved irrigation equipment and methods, and new varieties that permit higher planting densities and earlier achievement of maximum yields. Some of these changes (e.g., mechanical harvesting) may have had their main effect through saving costs rather than increasing yields per acre but yield-enhancing technical changes have certainly been important, as can be seen by the growth in yields over time (Figure 2.2).

Much of the technological change in almond production has been embodied in the trees and the land on which they are grown.[1] If information were available on the timing of the introduction and adoption of new technologies and their expected impacts on yield, such information could be incorporated into a yield model. Unfortunately, as is commonly the case, we do not have access to such information. Because adoption of new technology tends to occur gradually and smoothly over time, especially when that technological change is embodied in capital that changes gradually, it is often useful to represent changes in technology by linear time trends in yield models. That practice is followed here.

Vintage Capital—Yields and the Age Distribution

The yields of almond trees vary through their life cycle. For the first two or three years after planting, nut production is so low that harvesting is usually not justified. Yields for young trees have typically increased enough by the fourth year to justify harvesting; in fact, the California Agricultural Statistics Service (CASS) now classi-

[1] Rae and Carman (1975) discuss modeling supply response of perennial crops in the presence of this type of technological change.

fies almonds as nonbearing for the first three years and bearing in the fourth year.[2] Yields of bearing almond trees increase until about the eighth year when they tend to reach their maximum potential. This mature level of yields is sustained until approximately age 25, when yields begin to decline. The economically optimum age at which to uproot and replace trees depends primarily on the shape of the yield curve in the growth and decline phases, the biological relationship, but it also may be sensitive to economic variables, especially the interest rate, because a decision to replant involves foregoing some current yield from existing (declining) trees and waiting in order eventually to get higher yields from the replacements.[3]

If the age-profile of yields were stable over time, or if yields for trees of a particular age were known, as they were for the cling-peach orchards analyzed in French and King (1988), it would be reasonably easy to relate the average yield of a population of trees to its age distribution. In addition, a stable yield-age relationship implies that the optimal age at which to replace trees would be to a great extent constant, too. Complications arise, however, when new varieties are developed that have different shaped yield-age profiles, and when data to describe these changing profiles are unavailable. In addition, other aspects of new technology can change the yield-age relationship. For instance, mechanical harvesters stress trees so that their useful, productive life is shorter than if they were hand-harvested. While the gross relationship between the ages of trees and average yields will be reflected in the aggregate data to some extent, changing yield-age profiles over time mean that there may not be a stable or meaningful relationship between the age distribution and average yields. Thus, in the absence of data on the timing of technological change, it is not possible to have strong views on the relationship between average yields and the details of the age distribution of trees although one would expect to see some effects of changes in the age distribution on average yields.[4]

Alternate Bearing

Many tree crops are characterized by alternate (or biennial) bearing cycles in which a "high" year, with above-average yields is followed by a "low" year with below-average yields. Alternate-bearing cycles may be set off by unusual weather events. At the industry level, when weather is common across growers, alternate-bearing patterns show up in the aggregate data. Alternate-bearing patterns are likely to be less important in aggregate when different growers are subject to different weather patterns as will happen when production is geographically dispersed. The importance of alternate-bearing patterns, therefore, may diminish over time if an industry expands geographically and may become more important over time if an industry becomes more geographically concentrated. Alternate-bearing patterns may also be controlled to some extent by cultural practices, and different varieties may be more or less susceptible to alternate bearing.

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[2] An orchard is classified as "bearing" by CASS when it reaches an age at which it can normally be expected to produce a commercially significant quantity of the crop. Since this definition is a generalization, crops may be harvested from some orchards classified as nonbearing. For almonds, the number of years during which trees are identified as nonbearing has been changed twice: in 1972 the number of nonbearing years was reduced from 5 to 4, and then in 1980 it was further reduced from 4 to 3. Acreage data series used for the present study were adjusted to 4 nonbearing years for the total period of analysis.

[3] Olson (1986) discusses the economics of orchard replacement and presents an empirical example for almonds. In his appendix table 1 (p. 11), Olson shows yields, costs, and returns for a new almond orchard projected 50 years into the future.

[4] For instance, suppose that the introduction of denser plantings leads to an earlier achievement of maximum yields and higher maximum yields per acre and that this technology is introduced progressively over time as trees age and their replacement becomes economic. In this scenario, the data could show that *on average* immature trees (embodying higher yield for age) could yield more per acre than mature trees even though for each particular vintage of trees the yield-age relationship was in the other direction.

There are some questions about whether almonds are truly a biennial-bearing crop, and if so, to what extent. Despite these questions, the yield data in Figure 2.2 show some clear and strong year-to-year fluctuations in state-level yields. In addition, the fluctuations seem to have become larger over time. Whether these patterns are due to alternate bearing per se or some other reason, there are cycles in the data that must be incorporated in the yield model. Previous studies have used different treatments in attempting to capture alternate-bearing effects in yield models for almonds. Dorfman and Heien (1989) used the simple procedure of including a dummy variable for odd-numbered years as an intercept shifter (a year-to-year shift in the function) to represent alternate bearing. Dorfman, Dorfman, and Heien (1988) used a more sophisticated procedure that attempted to identify statistically whether the previous year's yield was above or below average and measured an alternate-bearing effect in current yields that depended on the size of last-year's yield relative to the average or expected yield. Both of these studies used county-level data to estimate yield models and in both cases, while the alternate- bearing effect was statistically significant, it was not very important as a component of the yield variation explained by the models.

Weather

California almonds are less susceptible to weather conditions than many other crops, in large part because they are grown under irrigation. For many crops, especially those grown under natural rainfall, a significant source of weather-related yield variation is rainfall variation during the growing season. California's dry summers are advantageous for many crops, including almonds, because they allow growers almost total control over the supply of water to the crop during the growing season. Still, for the California almond growing industry, rainfall is the most important weather variable affecting yields. This point is documented by Dorfman, Dorfman, and Heien (1988, p. 27):

> Almonds typically bloom in February and March during California's rainy season. Almond trees cannot self-pollinate, but must be pollinated by another almond variety. For this reason, almond orchards always contain at least two varieties of trees planted either in alternating rows or in two rows of one and one row of the other. Because cross-pollination is necessary, bees are vital to a good crop. If it rains too much during the bloom period, pollination by bees is inadequate and the almond crop is small.

Dorfman, Dorfman, and Heien (1988) and Dorfman and Heien (1989) found that February rainfall was a statistically significant explanatory variable in their yield models. While other weather conditions such as temperature may affect California almond yields, significant impacts of variables other than rainfall during the bloom period have not been isolated.

2.3 Forms for Yield Models

The Production Function

Dorfman and Heien (1989) assumed that the production function for almonds is of the fixed-coefficients, or Leontief, type. Thus:

$$Q_t = \sum_{i=0}^{n} y_{i,t} A_{i,t}, \tag{2.1}$$

where Q_t is production in year t, $y_{i,t}$ is the average age-specific yield per acre of trees aged i years in year t, $A_{i,t}$ is the number of acres of trees of age i years in year

t, and n years is the useful life of trees. As noted earlier, non-bearing almond trees in the age categories of 1, 2, and 3 years will have average yields equal to zero.

Age Distribution Effects

In year t, the age-specific yields of trees aged i years are affected by the values of systematic trends (T_t), random factors such as weather (W_t), alternate bearing patterns (D_t), and other factors represented by a random residual ($\epsilon_{i,t}$). A linear model with those components is:

$$y_{i,t} = \alpha_{i,0} + \alpha_{i,t}T_t + \alpha_{i,W}W_t + \alpha_{i,D}D_t + \epsilon_{i,t}. \tag{2.2}$$

If the slope coefficients and random effects in this model are constant across age categories of trees, then equation (2.2) may be written as:

$$y_{i,t} = \alpha_{i,0} + \alpha_T T_t + \alpha_W W_t + \alpha_D D_t + \epsilon_t. \tag{2.3}$$

Substituting this equation into equation (2.1) and dividing both sides by total bearing acreage (B_t), where total bearing acreage is the summation of acreage by age ($A_{i,t}$) for all tree ages in the bearing category, leads to the following equation for average yields per bearing acre (y_t):

$$\frac{Q_t}{B_t} = \sum_{i=4}^{n} \alpha_{i,0}\left[\frac{A_{i,t}}{B_t}\right] \alpha_T T_t + \alpha_W W_t + \alpha_D D_t + \epsilon_t. \tag{2.4}$$

In practice, bearing trees of different ages are usually aggregated into a smaller number of age classes—say young-bearing (YB_t), mature-bearing (MB_t), and old-bearing trees (OB_t), as in Alston, Freebairn, and Quilkey (1980), where $B_t = YB_t + MB_t + OB_t$—and a time-series econometric approach is used to represent the alternate-bearing component.[5] Thus:

$$y_t = \alpha_Y \phi_{Y,t} + \alpha_M \phi_{M,t} + \alpha_O \phi_{O,t} + \alpha_W W_t + \Phi(L)y_t + \epsilon_t, \tag{2.5}$$

where the ϕ's refer to the fractions of the acreage of bearing trees in the categories young (Y), mature (M), and old (O), respectively, and $\Phi(L)$ is a lag structure representing alternate-bearing effects on yields.

Alternate-Bearing Effects

The alternate-bearing component could be expressed as an arbitrary distributed lag. Experimentation with that idea led to the use of a second-order autoregressive model (two lags of yield) to represent alternate bearing. That is,

$$\Phi(L)y_t = a_1 y_{t-1} + a_2 y_{t-2},$$

which is equivalent to the alternative representation,

$$\Phi(L)y_t = b_1 y_{t-1} + b_2(y_{t-1} - y_{t-2})$$

where $b_1 = a_1 - a_2$ and $b_2 = -a_2$. This specification was superior to the use of lower- or higher-order lags in terms of yielding estimated coefficients with plausible signs and reasonable magnitudes.

How do we reconcile this structure with what we know about yields? One way to think about this is to decompose the yield into two parts, a long-run normal part (y^*), which is independent of any effects of weather, other random effects, or

[5]Dorfman, Dorfman, and Heien (1988) and Dorfman and Heien (1989) provide explicit examples of time-series approaches to pick up alternate-bearing effects.

alternate bearing, and the part due to the effects of current and past weather, other random effects, and alternate bearing. Then the model above may be expressed as:

$$y_t = y_t^* + \alpha_W W_t + \Phi(L) y_t + \epsilon_t,$$

where

$$y_t^* = \alpha_Y \phi_{Y,t} - \alpha_M \phi_{M,t} + \alpha_O \phi_{O,t} + \alpha_T T_t.$$

If the previous year's yield (y_{t-1}) was above the current long-run expected value (y_t^*), we would expect to see a negative alternate-bearing effect on yields in the current year. But last year's yield might have been above normal for a variety of reasons, unrelated to the alternate-bearing cycle. One measure of whether last year's yield was high (i.e., above its long-run normal value) due to alternate bearing is if it was higher than the yield two years previously (i.e., $y_{t-1} > y_{t-2}$). These types of arguments support the idea that to represent the current year's alternate bearing effect we need to include yields from at least two past years. The idea here is that the size of any alternate bearing effect on current yields depends on both (i) whether last year's yield was above its expected value, and (ii) whether it was above the value from the year before. Formally, this can be written as:

$$\Phi(L) y_t = \gamma_1 (y_{t-1} - y_t^*) - \gamma_2 (y_{t-1} - y_{t-2}).$$

Substituting this expression into the yield model and consolidating terms gives:

$$y_t = (1 - \gamma_1) y_t^* + \gamma_1 y_{t-1} + \gamma_2 (y_{t-1} - y_{t-2}) + \alpha_W W_t + \epsilon_t.$$

Substituting for y_t^* and simplifying leads to the following regression model:

$$y_t = \beta_0 + \beta_Y \phi_{y,t} + \beta_O \phi_{O,t} + \beta_T T_t + \gamma_1 y_{t-1} + \gamma_2 (y_{t-1} - y_{t-2}) + \alpha_W W_t + \epsilon_t,$$

where $\beta_Y = \alpha_Y(1 - \gamma_1)$, $\beta_O = \alpha_O(1 - \gamma_1)$, and $\beta_T = \alpha_T(1 - \gamma_1)$. Note that the mature age category (MB_t) has been dropped for estimation purposes to allow solution of the least squares regression model.

Interpretation of Coefficients

Some of the coefficients have ambiguous signs. The coefficient on trend is expected to be positive, and it is expected that the coefficients on weather (measured by rainfall during the bloom period), the fraction of young trees, and lagged yields all will be negative. In the event that yields are distributed symmetrically around the normal value due to alternate bearing (so that the magnitude of the "on" effect is equal and opposite the magnitude of the "off" effect) we would expect to find $\gamma_1 = -1$. This implies that this year's yield is expected to be below (above) normal by the same amount as last year's yield was above (below) normal. The coefficient on old bearing trees (OB_t) is also expected to be negative, reflecting the tendency for yields to decline for old trees.

The term involving the lagged change in yields is less intuitive. If it is measuring alternate bearing effects that are not measured fully by the first term then we would expect to find $\gamma_2 < 0$ also. However, it also might be picking up the effects of improving technology: an increase in yield last year, separate from alternate bearing effects, ought to persist to some extent into the current year. This would imply $0 < \gamma_2 < 1$. Thus, the expected sign of γ_2 is ambiguous.

2.4 Data for the Analysis

Almond Acreage Data

Data on total acreage, the acreage in various age categories, and plantings are reported by the California Agricultural Statistical Service. These data formed the basis for the series used for the analysis in this report. Appendix Table C2.1 includes the data on total acreage (A_t), bearing acreage (B_t), and the components of bearing acreage including young bearing trees 4–9 years old (YB_t), mature bearing trees 10–20 years old (MB_t), and old bearing trees, greater than 20 years old (OB_t) used to estimate the average yield equation.

Production and Yield

Data on annual production (Q_t) and yield per bearing acre (y_t), are also reported in Table C2.1. The units for yield are thousand pounds per bearing acre, kernel weight, calculated by dividing production by the corresponding figures for bearing acreage ($y_t = Q_t/B_t$).

Weather

Rainfall during the months of February and March can affect pollination and fruit-set. Rainfall in the principal almond-growing regions is represented by the monthly totals at the measuring stations at the Chico, Modesto, and Fresno airports. A simple monthly average of rainfall at these three stations is used as the index of monthly weather in February and March, reported in Table C2.1.

2.5 Estimation of the Yield Model

The yield model specified above was estimated with data for the 1950–1990 period using ordinary least squares methods. The equation was first estimated with variables for both February and March rainfall included. The estimated coefficient for March rainfall was not statistically different from zero ($t = 0.32$), thus the March rainfall variable was excluded and the equation was re-estimated. The final estimated equation for average annual California almond yield per acre is:

$$y_t = \underset{[t=1.86]}{0.5169} - \underset{[t=-6.33]}{1.199}\, y_{t-1} + \underset{[t=4.44]}{0.5099}\, (y_{t-1} - y_{t-2}) + \underset{[t=9.02]}{0.05648}\, T_t \quad (2.6)$$

$$- \underset{[t=-2.74]}{0.8045}\, yb_t + \underset{[t=3.08]}{1.817}\, ob_t - \underset{[t=-4.21]}{0.05149}\, FEBRAIN_t$$

$$R^2_{adj.} = 0.81 \qquad h = 1.19$$

where y_t is average annual per acre yield of almonds, 1,000 pounds kernel weight, T_t is a time trend with $1950 = 1, \ldots, 1990 = 41$, $yb_t = YB_t/B_t$ is the proportion of total bearing acreage that is 4 to 9 years of age, $ob_t = OB_t/B_t$ is the proportion of total bearing acreage that is over 20 years of age, $FEBRAIN_t$ is average February rainfall (sum of February rainfall (inches) measured at the Chico, Modesto, and Fresno airports divided by 3), and h is Durbin's h statistic.

The estimated yield model does a reasonably good job of tracking actual almond yields, as shown in Figure 2.3. The insignificant Durbin h statistic indicates that autocorrelation of the residuals is not a problem. All of the estimated coefficients, except for the old bearing trees variable, had the expected sign and were statistically significant at the 99% level. In particular, notice that the coefficient on lagged yield is close to -1.0, suggesting that yields tend to be symmetrically distributed around a normal value due to alternate bearing. In addition, the coefficient on the change in yield last year is positive and less than 1.0, consistent with the idea that some changes in yield persist to some extent for more than one year (e.g., those due to technological change or changes in age structure not captured by the other variables in the model). The coefficient on young-bearing trees is negative, as expected, and the coefficient on old-bearing trees, while positive, is plausible. The default category is mature trees (10–20 years old). As the proportion of young trees (4–9 years old)

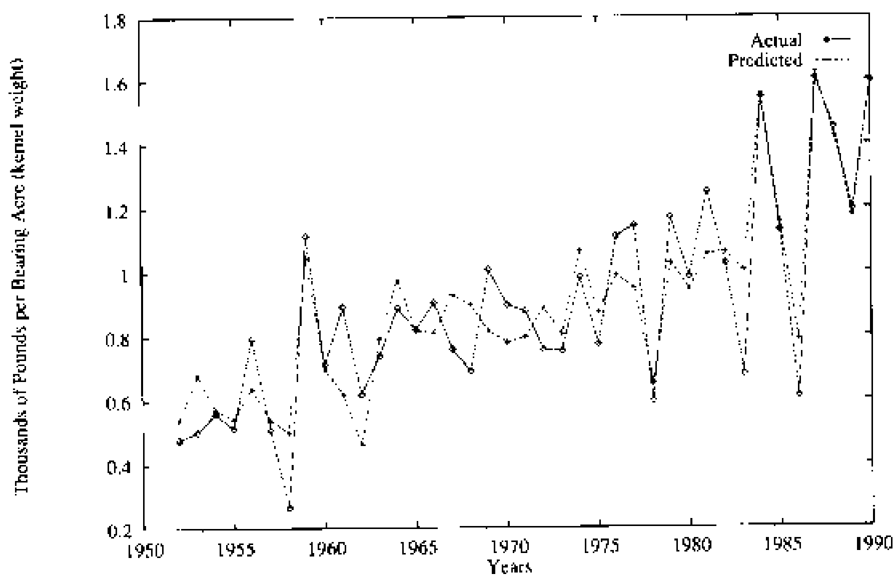

Figure 2.3: California Almond Yields, Actual and Predicted

rises, average yield falls, and as the proportion of old trees (over 20 years old) rises, average yield rises. The latter result was unexpected, but not implausible if (*i*) the majority of trees in the older category has been relatively young (i.e., trees at their peak rather than trees in decline) and (*ii*) if the less productive trees of a particular vintage are identified early and removed, hence never appear in the old-bearing group. Finally, as would be expected, increased February rainfall is associated with lower yields.

The estimated yield model compares favorably with previous models of almond yields published by Bushnell and King (1986), Dorfman, Dorfman, and Heien (1988), and Dorfman and Heien (1989). The present model offers two modifications of prior work on almond yields. First, it attempts to incorporate the effects of the age distribution of trees; second, it provides a more flexible structure for incorporating the impacts of alternate bearing.

2.6 Forecasting Average Almond Yields

The yield equation, which is one component of the industry model, can be used to make short-run yield forecasts. For example, yields can be forecast one year ahead by using current yields and average rainfall, or a forecast for the upcoming harvest can be made when February rainfall data are available. Longer forecast horizons will require the use of expected values for both lagged yields and rainfall. The use of the estimated yield equation to predict the fall 1993 harvest yields, y_{93}, can be illustrated with data available in March 1993. The values for the variables are: 1991 yield $y_{91} = 1.32$; 1992 yield $y_{92} = 1.54$; $T_{93} = 44$; proportion of young trees $yb_{93} = 0.1181$; proportion of old trees $ob_{93} = 0.2106$; and February rainfall $FEBRAIN_t = 4.59$. When these variables are entered in the equation, the estimated 1993 average yield is 1,320 pounds per acre (kernel weight). An earlier forecast of 1993 yields (made after the 1992 harvest but before February rainfall data were available) using the average of rainfall for the 1950–1990 period (2.5625 inches) would be 1,424 pounds per acre. The actual yield in 1993 was 1,356 pounds per acre.

It is a small step from the yield forecast to a total-production forecast. The number of acres of bearing almonds in California in any year can be estimated accurately based on previous bearing acreage, plus plantings four years previously, less estimated current removals. Thus, the harvest forecast is primarily dependent on the yield forecast. Bearing acreage for 1993 is estimated at 360,000 acres. Based on average rainfall, a 1993 harvest forecast of 512.6 million pounds could have been made in the early fall of 1992 after 1992 crop yields were known. Once the actual February rainfall was known in early March 1993, the forecast would be 475.2 million pounds.

CASS uses a sampling procedure (essentially monitoring the nut count on selected trees) to predict the almond harvest, usually with reasonably good accuracy. The statistical yield model developed in this study can provide a good supplement to the CASS procedure. The CASS subjective forecast, released on June 10, 1993, was for a 1993 harvest of 520 million pounds. The CASS objective forecast released on July 1, 1993, was for a harvest of 470 million pounds. Note that the latest CASS forecast is quite similar to the March forecast developed in this study, but the yield model forecast was available several months earlier. In particular, the model forecast has some advantages in timing relative to the CASS procedure: harvests can be predicted as soon as February rainfall data are available, and harvests can be simulated well in advance of the bloom by positing various rainfall scenarios.

3. CALIFORNIA ALMOND ACREAGE RESPONSE

3.1 Introduction

The California almond industry has experienced phenomenal growth in planted acreage since World War II. In 1946 there were 109,000 acres of trees (90,000 bearing). Since then, the industry quadrupled in size to 432,000 acres (411,000 bearing) in 1990. At an average value of approximately $7,000 per acre, this amounts to a total investment in productive capacity of over $3 billion. As shown in Figure 3.1, most of the growth in planted area of almonds occurred during the past thirty years, especially during the decade 1966–1975.

The purpose of this supply response analysis is to model historical changes in almond acreage and output with a view to (*i*) explaining past changes and (*ii*) predicting future responses to alternative industry policies. Much—if not all—of the almond industry's supply response to price is the acreage response and, for this reason, most studies have assumed that yields are unaffected by prices of inputs and output. Thus, the emphasis of the analysis will be on modeling the investment response. Results of this type of analysis can have several uses. In the context of the almond industry, one of the most important uses is to evaluate the implications of the industry using the reserve provisions of the marketing order to collectively restrict sales to the primary market and increase prices. A key to understanding the implications of using the marketing order to increase price is the *size* of the long-run supply response (i.e., the total eventual response to a price change) and the *rate* at which the industry adjusts towards a new equilibrium (i.e., the timing of response). Together these factors determine short-run profits that can be generated by market allocations that lead to a higher average price to producers, and the duration of those profits which will eventually be eroded by supply response—either domestically or overseas—to the higher prices.

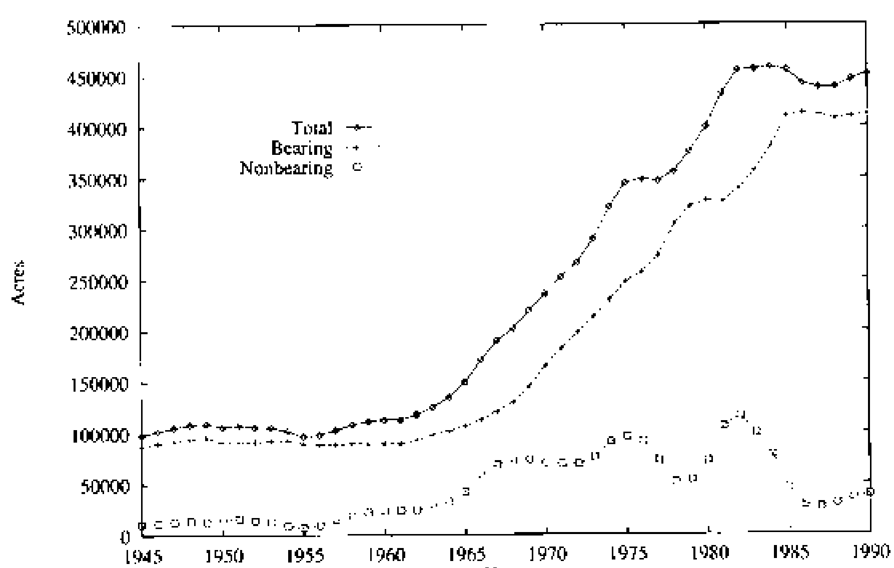

Figure 3.1: Total, Bearing, and Non-bearing Acreage of California Almonds

The analysis in this section has three main components. First, a qualitative analysis of the situation of the industry (its technology, institutions, structure, factor use, and conditions of factor supply) leads to a view that the long-run supply elasticity (response to price) is very elastic, possibly perfectly elastic. This view leads to a restatement of the problem as one of explaining (*i*) why the observed supply response is less than perfectly elastic in the short and intermediate run and (*ii*) measuring the duration of the short run as the period during which supply response is less than perfectly elastic and, thus, in which profits can be generated by market allocation policies that lead to greater average revenues. Second, models of supply response are reviewed and developed. Two main threads are explored in this development including (*i*) the general literature on perennial crops supply response, and (*ii*) an alternative approach, following that of Dorfman and Heien (1989), that uses a neoclassical investment model to study investment responses in the almond industry.[1] The third component is empirical analysis, based on the model development.

The final output from the supply analysis is summarized in terms of a set of equations that can be used to represent the supply side of the almond economy. These equations may be used to derive (*i*) supply (acreage and output) response to price changes over various lengths of run, (*ii*) supply response to other variables, (*iii*) a measure of the number of years required for full adjustment to a permanent price change, and (*iv*) projections of the time path of supply response to a simulated price increase (or change in other economic variables).

3.2 A General View of Supply Response

Determinants of Long-Run Supply Elasticity

Total industry supply is the sum of the outputs of all individual firms in the industry. In a competitive industry, individual firms are unable to influence the prices of any of the inputs or outputs because every firm is small relative to the total industry. If all inputs were freely variable, and there were constant returns to scale at the farm firm level (i.e., a doubling of all inputs, including human capital, leads to a doubling of output), individual supply response would be perfectly elastic (responsive). In reality, the supply response decisions of individual firms—and farm sizes—are constrained by quasi-fixed inputs (inputs that are fixed in the short run but which may be varied in the longer run, such as bearing acreage). While by definition there are no fixed inputs in the long run, managerial capacity of the farm firm may be relatively fixed for intermediate periods and this is the factor that constrains both the optimal firm size and the total size of the industry.[2]

The industry supply response function is a reflection of the supply response decisions of individual firms (including current firms and potential entrants to the industry) modified by their collective impacts on the prices of variable factors of production that are specialized in the industry. While prices of variable inputs are exogenous to the individual firms in a competitive industry (since they are all price takers in input and output markets), firms can affect prices of inputs (and outputs) by their collective actions. This occurs when the industry faces an upward-sloping

[1] The general perennial crops supply response literature includes, for example, studies by French and Bressler (1962), French and Matthews (1971), Rae and Carman (1975), Alston, Freebairn, and Quilkey (1980), French, King, and Minami (1985), French and King (1988), Nuckton, French, and King (1988) and French and Willett (1989). Several others are reviewed by Askari and Cummings (1976, 1977). The neoclassical investment approach had been used previously for other tree crops (for example, by Wickens and Greenfield (1973) for coffee and by Akiyama and Trivedi (1987) for tea).

[2] In the longer run, differences in human capital among farmers are likely to be the primary determinants of persistent differences in farm size, and to account for an *equilibrium distribution* of optimal farm sizes (Sumner 1986).

supply curve of one or more inputs so that factor use by the industry as a whole affects factor prices. A common example in agriculture is land that is regarded as being (approximately) fixed in total supply, even though individual firms can buy as much land as they choose without significantly affecting its price.[3] Thus, even when it is reasonable to expect the long-run supply response (of firms or the industry) to be perfectly elastic, the intermediate-run industry supply response function can be less than perfectly elastic for a number of reasons. These include fixed factors at the firm level and quasi-fixed factors at the industry level.

In the almond industry, there are few specialized factors that are likely to lead to important constraints on the industry's supply response in the longer run. Suitable land (with irrigation water rights) is relatively abundant and it is unlikely that a significant expansion in almond acreage would have important effects on the price of irrigated land in California.[4] The industry is also a relatively small user of agricultural chemicals, equipment, other purchased inputs, and agricultural labor, and might reasonably be regarded as a price taker in the markets for most purchased inputs, even in the short run. The supply of nursery stock could be limited in the short run. However, for the types of reasons presented above, the nursery industry is likely to be a constant-cost industry in the long run (i.e., able to supply the almond industry's requirements at constant prices). Thus, the role of an upward-sloping supply curve in the nursery stock industry, in modifying supply response in the almond industry, is likely to be short-lived. It is, however, one of the many factors that lead to lags in almond supply response to price changes (i.e., a contributor to the short-run dynamics of supply response rather than a source of longer-run inelasticity of supply).

There are two other factors that could limit expansion of the industry in response to a price increase in the short and intermediate run. They are (*i*) the availability (and willingness) of people who have the necessary expertise and skills (or human capital) to enter the industry in response to an increase in profitability, and (*ii*) the availability of capital to finance an investment in new almond trees by an existing or would-be grower. In agriculture, the traditional view has been that the supply of investment capital is linked quite closely to the supply of capital owned by farmers—to a great extent capital in agriculture is the equity of farmers rather than the equity of general investors, or is constrained by the equity of farmers under bank lending rules. Farm firms typically cannot issue securities on national markets, and must instead rely for outside finance on banks or other intermediaries.[5] Individual firms are likely to face an upward-sloping supply of capital for investment in particular enterprises, such as almond production, because the risk of default is likely to increase as the proportion of debt to equity increases. Thus, the supply of capital to the industry will be limited to the extent that the supply of farm operators is limited (or because the supply of equity to the fixed supply of farmers is limited). One view, then, is that in the intermediate run, the supply of capital to finance investments in almond production is upward-sloping because the supply of farm operators to the industry is less than perfectly elastic. These constraints are less likely to be effective over time and the long-run supply curve should be perfectly elastic.

In summary, the supply response in a competitive industry is conditioned by

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[3]Although agricultural land may be regarded as fixed in *total* supply, its supply to a particular industry (such as almonds) may be perfectly elastic.

[4]The almond industry uses only a small fraction of the total irrigated land available in the counties or regions where almonds are grown in significant quantities: Butte, Colusa, Contra Costa, Glenn, Solano, Sutter, Tehama, Yolo and Yuba counties in the Northern Region, Fresno, Madera, Merced, San Joaquin and Stanislaus counties in the Central Region, and Kern, Kings, San Luis Obispo and Tulare counties in the Southern Region.

[5]There are notable exceptions to this traditional view in the California almond industry with the involvement of firms such as Paramount Farms, Inc. and Dole, Inc. in almond production.

its production technology and the supply of inputs to the industry. In the almond industry, it is reasonable to assume approximately constant returns to scale in the long run, at the industry level, as an artifact of competition (e.g., Diewert (1981)). Combining constant returns to scale with price-taking behavior in the factor markets, by firms and the industry as a whole, suggests that the industry is one of approximately constant cost (i.e., perfectly elastic supply) in the long run. However, in the short run, there are many fixities in almond production and these are responsible for the important short-run inelasticity of supply response and dynamics. Some of these dynamics and fixities are due to the biological and technological constraints on adjustment of investments and output in response to price changes. Some are more behavioral and economic. As the length of run is extended, the importance of the technological and biological sources of fixities becomes smaller and, in the intermediate run, the key source of less than perfect elasticity of supply may be human capital—the ability and willingness to grow almonds--both directly and through its effects on the supply of capital to finance investments in almond production.

Conceptual and Measurement Issues for Supply Response Models

Cassels (1933), in a classic *Journal of Farm Economics* article, identified the key issues in analyzing supply response, and these have remained largely unchanged in spite of the major advances in theory, availability of detailed data, computing power, and econometric estimation techniques.[6] In fact, a significant portion of the rather extensive literature on supply analysis during the past 60 years has concerned treatments for problems raised by Cassels.[7] Primarily these efforts have related to the dynamics of response and the formation of expectations. Early models used naive expectations (the expected price is the current price or last period's price) and typically assumed instantaneous adjustment. One major development was the introduction of models in the late 1950s to represent adaptive expectations and partial adjustment (dynamics) in supply response, and these models have predominated in the literature since—not without some critics.[8] Some of the more recent work has attempted to incorporate rational expectations.[9] There have also been attempts to specify dynamics that are attuned to the biological and technological constraints on production—e.g., Jarvis (1974) for beef cattle, Chavas and Johnson (1982) for broilers and turkeys, and Chen, Courtney, and Schmitz (1972) for milk. This type of approach has been a particular feature of many of the models for perennial crops.[10] A few studies have attempted to incorporate government commodity policy variables (e.g., Houck, Abel, Ryan, Gallagher, Hoffman, and Penn (1976), Lee and Helmberger (1985)) or risk considerations (e.g., Just (1974), Traill (1978))

[6]In particular, Cassels (1933) discussed the time character of supply functions, the issue of asymmetric supply response (due to asset fixities), the supply-response price and the idea of price expectations, the question of the choice of supply response variable (acreage or output), the roles of weather and technical change in supply response, and the treatment of ceteris paribus conditions including prices of inputs, prices of competing products, and technology. Cassels' views on the difficulties of estimating supply functions have been echoed in much of the subsequent literature (e.g., Schultz (1956) and Colman (1983)).

[7]There have been several reviews of the methodological approaches to supply response analysis and issues to be addressed in specifying supply response models since Cassels (1933), including, for example, Nerlove (1960), Heady, Baker, Diesslin, Kehrber, and Staniforth (1961), Cowling and Gardner (1963), Askari and Cummings (1976, 1977), Shumway and Chang (1977), Nerlove (1979), and Colman (1983).

[8]Reviews of the use of this type of model have been written by Askari and Cummings (1975, 1977) and Nerlove (1979).

[9]For example, Eckstein (1984, 1985) and Holt and Johnson (1989).

[10]For example, French and Bressler (1962), French and Matthews (1971), Wickens and Greenfield (1973) Rae and Carman (1975), Alston, Freebairn, and Quilkey (1980), French, King, and Minami (1985), Akiyama and Trivedi (1987), French and King (1988), Nuckton, French, and King (1988), French and Willett (1989), and Dorfman and Heien (1989).

in supply models for annual crops.

Synopsis

While some progress has been made in the arts of supply analysis, as Colman's (1983) thorough review indicates, the main issues that must be addressed in supply response analysis continue to be those identified by Cassels (1933), and they continue to be difficult. This conclusion is supported by the surprisingly low estimates of long-run supply response elasticities obtained by most studies. The apparent systematic downward bias in estimated long-run supply elasticities is almost surely a consequence of misspecified dynamics and expectations, and this is likely to be especially important for perennial crops for which the issues of dynamics and timing are of overwhelming importance, both directly and in the definition of expectations.[11] As Cassels (1933) predicted, it has proven to be virtually impossible to estimate a long-run supply response. The following discussion will focus on ways to specify supply models for almonds so as to get the best possible estimate of the longer-run acreage adjustments to price changes.

3.3 Analysis of Supply Response for Perennial Crops

Perennial crop production requires a relatively large capital investment committed over a number of years. Since production decisions are similar to other investment decisions with long planning horizons, the appropriate theoretical framework for perennial crop supply response is one based on investment theory. One can begin with the idea that the expansion of capital stock, or net investment, takes place because of a difference between the actual and desired capital stock. For a perennial crop, the difference between plantings and removals in a given year is net investment. Investment may be based on expected profits or on the expected present value of net revenue over the life of the investment.

The total annual production of a perennial crop, such as almonds, is the product of the bearing acreage and the yield per acre. Thus, the empirical estimation of supply response requires expressions for both bearing acreage and average yield per acre. Specification and estimation of an equation for annual bearing acreage is more difficult than for average yields because of problems associated with determining the appropriate conceptual framework, problems associated with data, and the difficulties of selecting proxies for unobservable variables. Significant time lags between decisions to plant and production lead to problems of modeling expectations about the future profitability of a crop and the actions taken in response to these expectations.

The total bearing acreage of a perennial crop in any year t results from expectations and decisions made over a period of time extending beyond the expected life of a typical tree. The bearing acreage in the current year t is the bearing acreage the previous year $(t-1)$, plus the addition of new bearing acreage from plantings made k years previously (where k is the number of years required from planting a tree until it is classified as bearing), minus removals of trees during the current year (t). This relationship can be expressed as

$$B_t = B_{t-1} + PL_{t-k} - R_t,$$

where B is bearing acreage, PL is new plantings, R is removals, and k is the number of years after planting until the orchard is bearing. In this study, California almonds are classified as non-bearing for the first four years after planting $(k=4)$.[12] Thus,

[11] A downward bias in supply elasticities could also be due in part to the facts that many agricultural prices tend to move together and the typical analysis does not properly control for cross-price effects.

[12] See footnote 2 in Chapter 2.

a tree planted in year $t-4$ will be classified as bearing in year t. It is important to note the time at which the variables are measured (calendar year, crop year, etc.) so that the acreage relationships are consistent. If one focuses on the bearing acreage at the time of harvest, which is reasonable given that production for a given year is the product of bearing acreage and average per acre yields, then the plantings and removals all occur after the harvest in year t-1 and before harvest in year t, with the time after harvest designated as occurring in year t.

The bearing acreage relationship presented above assumes that all removals are from bearing acreage. To recognize that some removals may be from nonbearing trees due to disease or other causes, the bearing acreage relationship is

$$B_t = B_{t-1} + PL_{t-k} - R_t - RP_{tk},$$

where RP_{tk} is the number of acres of new planting in $(t-k)$ removed before year t. This can be expressed more conveniently as

$$B_t = B_{t-1} + a\,PL_{t-k} - R_t,$$

where a is a proportion, slightly less than 1.0, that accounts for the small amount of removals from nonbearing trees.[13] Since data on removals by age category are typically not available, most empirical work uses $a = 1.0$.

Approaches to estimation of this relationship have included (i) separate estimation of new plantings and removals, which are then used in the relationship above to calculate bearing acreage, or (ii) estimation of a change in bearing acreage relationship, where

$$\Delta B_t = B_t - B_{t-1} = a\,PL_{t-4} - R_t.$$

Separate estimation of the planting and removal relationships requires appropriate data. Because of problems with the availability and quality of planting and removal data, some researchers have concentrated on directly estimating the change in bearing acreage relationship. When acreage data are available, bearing acreage is typically measured more accurately than is nonbearing acreage, plantings, or removals.

Most researchers modeling perennial crop supply response have used an approach similar to that presented by French and Matthews (1971), which attempts to explain the behavior of producers as a group based on assumptions about individual producer behavior. French and Matthews' basic assumption is that producers have a desired level of production of a commodity, based on the expected profitability of the commodity and the expected profitability of alternative land uses. In this model, expected profitability is a function of expected prices and costs. Profit expectations lead to a desired level of production for a future year t, which leads to a desired level of bearing acreage for year t, and this leads to desired new plantings in year $(t-k)$. Since expectations variables were unobservable and some data series were not available, French and Matthews (1971) simplified their model and developed proxy variables.[14] The application of the model was to asparagus.[15]

Table 3.1 summarizes the similarities and differences in the approaches used in models of perennial crops supply response. As shown in the table, the empirical estimation of the new plantings relationship for a perennial crop typically uses one of two options for the dependent variable: (i) total acres planted during year t, or (ii) total acres planted in year t as a proportion of acreage of the crop (either bearing acreage or total acreage).

[13] French, King, and Minami (1985, page 221) found small percentages of cling peach plantings removed each year before reaching bearing age.

[14] Alston, Freebairn and Quilkey (1980) showed that alternative formulations of the desired investment model, of which French and Matthews'(1971) model is one example, can all lead to the same reduced-form equation for estimation.

[15] An improved version of the model applied to asparagus is contained in French and Willett (1989).

Table 3.1: Summary of Main Perennial Crop Supply Response Studies in the Literature

Authors	Commodity	Dependent Variable	Independent Variables
PLANTINGS EQUATIONS:			
French and Bressler (1962)	Lemons	$\frac{PL_t}{B_{t-1}}$	$NATR_{t-1,t-5}$, $B(> 25\text{y.o.})/B_{t-1}$
Rae and Carman (1975)	Apples(NZ)	PL_t	$DATR_{t-4,t-7}$
Alston, Freebairn and Quilkey (1980)	Oranges (Aust.)	PL_t	$DATR_{t-1,t-5}$, NB_{t-1}, B_{t-1}, R_{t-1}
Carman (1981)	Almonds	PL_t	$DAP_{t-1,t-2}$, tax dummy, labor index
French, King, and Minami (1985)	Cling Peaches	$\frac{PL_t}{A_{t-1} - R_{t-1}}$	$DANR_{t-1,t-3}$ (and squared), t, $E(Q)$, $(A_{t-1} - R_{t-1})$, dummy
Bushnell and King (1986)	Almonds	PL_t	$DATR_{t-1,t-2}$, NB_{t-1}, B_{t-1}, labor index
French and Nuckton (1991)	Raisin Grapes	$\frac{PL_t}{A_{t-1} - R_{t-1}}$	$DANR_{t-1,t-3}$
ACREAGE CHANGE EQUATIONS:			
French and Matthews (1971)	Asparagus	$B_t - B_{t-1}$	$(DP_{t-1} \cdot AB_{t-1,t-5})$, $DAP_{t-2,t-3}$, $AB_{t-1,t-5}$, $AB_{t-2,t-6}$
Carman (1981)	Almonds	$A_t - A_{t-1}$	$DAP_{t-1,t-2}$, A_{t-1}, tax dummy, labor index
Thor and Jesse (1981)	Navel Oranges	$B_t - B_{t-1}$	DNR_{t-4}, DNR_{t-5}, DNR_{t-6}, price risk, Y_{t-4}, urban
Thor and Jesse (1981)	Valencia Oranges	$B_t - B_{t-1}$	DNR_{t-5}, DNR_{t-6}, DNR_{t-7}, price risk, Y_{t-4}, tax
Albisu and Blandford (1983)	Oranges (Spain)	$A_t - A_{t-1}$	DP_{t-1}, $B(> 7\text{ y.o.})$, $B(> 14\text{ y.o.})$, dummy
Kinney et al. (1987)	Lemons	$B_t - B_{t-1}$	$DATR_{t-3,t-6}$, $DATR_{t-6,t-9}$, tax risk, risk_{t-1}
Dorfman and Heien (1989)	Almonds	$\frac{A_t - A_{t-1}}{A_{t-1}}$	PV_{t-4}, PV_{t-5}, PV_{t-6}, PV_{t-7}, PV_{t-8}, $V(PV)$
REMOVALS EQUATIONS:			
French and Bressler (1962)	Lemons	$\frac{R_t}{B_t}$	constant
Rae and Carman (1975)	Apples (NZ)	R_t	B_{t-1}, DP_{t-1}
Alston, Freebairn and Quilkey (1980)	Oranges (Aust.)	R_t	B_{t-1}
French, King and Minami (1985)	Cling Peaches	$\frac{R_{it}}{A_{it}}$	$DANR_t$, green drop dummy, early removal dummy
Bushnell and King (1986)	Almonds	R_t	$DATR_{t-1,t-2}$, NB_{t-1}, B_{t-1}, labor index
French and Nuckton (1991)	Raisin Grapes	$\frac{R_t}{B_{t-1}}$	$DATR_{t-1,t-2}$

Notes: A_t, B_t, NB_t and R_t denote total, bearing, nonbearing, planted, and removed acreage in year t. In the other variables, N = nominal, D = deflated, NR = net revenue, TR = total revenue. A before a variable denotes average, with the range of the average indicated by the subscripts. For example, $DANR_{t-1,t-5}$ is the deflated average net revenue over the period $t-1$ to $t-5$. $AB_{t-1,t-5}$ denotes average bearing acreage during that period. "y.o." = "years old."

Studies that are based on the premise that new plantings are a function of expected profitability of the crop often assume that profit expectations are based on recent experience. Thus, variables to measure recent profitability may take the form of annual prices, total revenue, total revenue minus costs, and indexes of costs. These variables usually enter the equation as moving averages ranging from one to five years, with the length of the moving average typically based on the formulation that provides the best statistical results. Other variables to measure profit expectations or changes in expectations due to technology or government programs (taxes, labor, and marketing orders) have also been employed. Some studies have also included variables for recent bearing and nonbearing acreage, assuming that increases in the stock of young bearing and nonbearing trees will depress profit expectations and plantings.

Trees may be removed in response to a number of factors, with declining productivity over time being quite important. Other factors such as urban expansion, a damaging freeze, disease, insect problems, or short-run profit expectations may also affect removals. Since most empirical studies do not have detailed data on the age distribution of trees and often face problems associated with reliable reporting of annual removals, the estimated removals equations tend to be abbreviated. As shown in Table 3.1, the removals equation may include only one or two variables or, in the extreme, may be a constant percentage of bearing acreage (e.g., French and Bressler (1962)). When detailed data on the age distribution of trees are available, one may obtain very good estimated removals relationships based on the age of the trees (as done by French, King, and Minami (1985), for example, in their study of the cling peach industry).

Approximately half of the studies reviewed have estimated a change in acreage (usually bearing acreage but sometimes total acreage) relationship that combines plantings and removals, with appropriate lags, into a single equation. As mentioned previously, this approach is often taken in response to the availability and/or the perceived quality of plantings and removals data. Of the perennial crop acreage data typically available, bearing acreage is generally the most reliable. Specification of a change in bearing acreage equation requires variables associated with both plantings and removals, with lags to account for the time required for plantings to reach bearing age. When plantings are a function of lagged average revenues, the lags associated with change in bearing acreage in year t can be quite long.

3.4 Modeling California Almond Supply Response

Yield Models

Most perennial crops supply response models decompose output into yield and acreage components. Estimation of the almond yield equation was discussed in Chapter 2. It remains to specify models to explain the changes in almond acreage resulting from planting and removal decisions.

Models of Plantings

Two alternative approaches to modeling almond plantings were investigated. The first, based on features presented by French and Bressler (1962), French and Matthews (1971), French, King, and Minami (1985) and Alston, Freebairn, and Quilkey (1980), as reviewed above, assumes that annual plantings are a linear function of expected annual profitability, the previous year's acreage, and current removals. The model, designated as the Traditional Model (TM), is specified as

$$PL_t = \beta_0 + \beta_1\pi_{t-1} + \beta_2\pi_{t-2} + \beta_3\pi_{t-3} + \beta_4\pi_{t-4} + \beta_5 K_{t-1} + \beta_6 R_t + \epsilon_t, \quad (3.1)$$

where PL_t is plantings in year t, π_t is state-average net (after-tax) returns per acre in year t, K_t is the stock of trees in year t, and R_t is removals in year t. This incorporates features of the models used by French and Bressler (1962), French and Matthews (1971), Alston, Freebairn, and Quilkey (1980), and French, King, and Minami (1985).

The second model, designated as the ENPV (Expected Net Present Value) Investment Model, is derived from the earlier work of Dorfman and Heien (1989). It is based on the assumption that the amount of investment (I) depends on the expected present value of a stream of net profits derived over the productive life of an investment. The annual stream of net profits (which may be negative for several years) is adjusted for tax liabilities and discounted back to its present value to arrive at a single dollar value. This expected net present value is the amount of money a risk-neutral investor would accept in exchange for an acre of almonds which are about to be planted. It is assumed that an increase in the expected net present value per acre of almonds planted will lead to an increase in plantings.

Changing income tax laws can significantly affect the after-tax cost of almond orchard development as well as the income stream from the asset. There were four major changes in tax laws with potential impacts on almond investment decisions during the period of analysis. These included (*i*) the requirement that almond development costs be capitalized during the first four years after planting, effective in 1970; (*ii*) rules effective in 1976 that required syndicates to capitalize development costs for all perennial crops; (*iii*) the Economic Recovery Tax Act of 1982 that increased the investment tax credit and reduced the depreciation recovery period to five years for trees; and, (*iv*) the Tax Reform Act of 1986 that lengthened depreciation recovery periods, required capitalization of development costs for all perennial crops, terminated the investment tax credit, further restricted agricultural tax incentives for non-farm investors, and reduced marginal tax rates.

The basic investment function postulated for this study is

$$I_t = \beta_0 + \beta_1 ENPV_t$$

where the coefficients β_0 and β_1 are the reduced form parameters when investment cost is a quadratic function of investment and $ENPV_t$ is the expected net present value of an investment made in year t.[16] This equation can be estimated by linear regression techniques using either gross investment (plantings) or net investment (plantings minus removals). Because of the time required for investment decisions in almond development, adjustment costs, and possible short-run constraints (such as limited nursery supply of tree stock), the basic investment function is expanded to a partial adjustment investment model of the form

$$I_t = \gamma(\beta_0 + \beta_1 ENPV_{t-1}) + (1-\gamma)I_{t-1}, \qquad (3.2)$$

where γ is the fraction of the desired change in investment that is accomplished in year t.

Models of Removals

Many studies have used a very simple removals model that assumes a constant proportion of total acreage (or of bearing acreage) is removed from production each year—e.g., French and Bressler (1962), Alston, Freebairn, and Quilkey (1980), and

[16] The quadratic investment-cost function captures the increasing costs of high levels of plantings, due to factors such as limited supplies of nursery stock, planting teams, or the management expertise needed to increase capacity. Profit maximizing growers will then increase plantings to the point where the expected net present value of the marginal orchard equals the change in total investment costs, which with quadratic costs is a linear function of the level of plantings. Rearrangement of this profit-maximization condition gives the equation above.

Dorfman and Heien (1989). In many cases this type of specification has been taken as a default option because an attempt to model removals as an economic response has been unsuccessful.

In principle, a removals model can take the same form as the investment model. That is, a decision to disinvest in an existing area of almond trees—to remove the trees—will depend on the expected net present value of the benefits from retaining the trees in production, the opportunity costs of foregone profits from alternative uses of the land, and the costs of removing the trees from production. Because yields decline as trees age, the decision to remove trees from production will depend on their age (expected age-specific yields) and prices and costs. The optimal age at which to remove trees from production should vary with changes in prices and costs and thus, for a given population of trees, the average removal rate ought to vary according to economic conditions and the age distribution. As a further complication, there may be differences in the nature of removals response to changes in prices and costs between (*i*) removals of trees to replant with almonds, and (*ii*) removals of trees to free the land for some alternative use. Similarly, plantings as replacement investment may involve different costs, and therefore different responses, than altogether new plantings.[17] As with plantings, two models of removals were specified, a traditional model and an ENPV model.

The traditional removals model included the same basic explanatory variables, excluding lagged removals, as did the traditional plantings model.[18] The removals equation is specified as

$$R_t = \beta_0 + \beta_1 \pi_{t-1} + \beta_2 \pi_{t-2} + \beta_3 \pi_{t-3} + \beta_4 \pi_{t-4} + \beta_5 K_{t-1} + \beta_6 T_t + \epsilon_t, \qquad (3.3)$$

where R_t is acres removed from production in year t, π_t is state-average net (after-tax) returns per acre in year t, K_t is total acreage in year t, and T_t is a time trend.

Since it is reasonable to expect removals to be related to the ENPV of an acre of almonds and to the age of the trees, the following investment model is suggested for removals:

$$R_t = \beta_0 + \beta_1 ENPV_{t-1} + \beta_2 OLD_{t-1}, \qquad (3.4)$$

where R_t is removals in year t and OLD_{t-1} is acres of trees nearing the end of their productive life in year $t-1$. This model is similar to the removals model in French and King (1988), except that they were able to estimate removals separately for each age class.

3.5 Data for the Analysis

Data were obtained on a variety of economic variables to permit the estimation of the various components of supply response. These data are listed in Appendix Tables C2.1, C3.1, C3.2 and C3.3.

Almond Acreage Data

Data on total acreage, the acreage in various age categories, and plantings are reported by the California Agricultural Statistical Service (CASS). These data are not always internally consistent. For instance, the number of acres in a particular age class (say 5-year-old trees) reported in year $t+5$ is sometimes greater than

[17] Akiyama and Trivedi (1987) distinguish between planting for replacement and net investment. Olson (1986) provides information on the effects of changes in economic variables such as interest rates and tax laws on the economics of uprooting and replanting almonds.

[18] All of the models, whether or not traditional, use lagged values of prices in the construction of the incentive variables (expected net present value or profitability). The differences between the models is in the ways the underlying data are manipulated and in their interpretation.

the number of trees that were reported as planted in year t. In some instances the reported area of new plantings is less than the reported increase in total tree numbers for the same year, implying negative removals of trees during that year. CASS does not adjust prior total acreage and nonbearing acreage to account for under-reported plantings in prior years. Thus, it was necessary to adjust the data for plantings, acres of nonbearing trees, and removals to eliminate gross violations of the laws of nature. The CASS series on bearing acreage were taken as given. Trees reported in each age class each year were recorded for ten years after the planting date to find the maximum reported acres planted for each year; the maximum was used as the plantings for that year. Plantings were used to calculate nonbearing acreage, total acreage and removals. Because of these adjustments, the calculated acreage data used for the analysis differ from those reported by CASS. In most cases the necessary adjustments were relatively minor, but the fact that they were necessary adds an explicit reason for concern about the quality of the disaggregated data. One of the advantages of the more aggregative (net investment) models that consider only changes in total acreage is that they are less vulnerable to measurement errors of these types.

Tables C2.1 and C3.1 include data on total acreage (A_t), plantings (PL_t), removals (R_t), nonbearing acreage (NB_t) with trees 0–4 years old, bearing acreage (B_t), and the components of bearing acreage including young bearing (YB_t) trees 5–9 years old, mature bearing (MB_t) trees 10-20 years old, and old bearing (OB_t) trees, greater than 20 years old. Removals are computed as

$$R_t \equiv PL_{t-4} + B_{t-1} - B_t, \tag{3.5}$$

which is an accounting identity reflecting that the change in bearing acreage must equal the plantings made 4 years ago minus the current removals. In our calculations, removals according to this formula are always positive numbers (by construction) while removals obtained using just the CASS data series can be negative.

Production and Yield

Data on annual production (Q_t) and yields per bearing acre (y_t), are reported in Table C2.1. The figures for yield are thousands of pounds per bearing acre, kernel weight, calculated by dividing the CASS figures for total production by the corresponding figures for bearing acreage ($y_t = Q_t/B_t$).

Almond Prices and Average Revenues per Acre

The data on prices for almonds (p_t) in Table C3.2 are expressed in dollars per ton, kernel weight, farm-gate equivalent. To compute average revenue per bearing acre, the price was multiplied by the average yield per bearing acre. To express this in real terms, the nominal revenues per acre were deflated by the GNP deflator based 1977 = 100 (D_t). Thus $G_t = p_t y_t / D_t$.

Establishment and Production Costs

The first step in calculating the net present value of an acre of almonds is to determine the expected establishment costs. Establishment costs for the first five years of an almond orchard are calculated based on figures compiled by the University of California Cooperative Extension Service. Crop budgets for the years 1969, 1981, and 1988 were used. A cost index for prices paid by farmers was employed to estimate establishment costs for years between budget updates. To smooth this series, costs for years between published budget years are estimated as a weighted average of the budgets directly before and directly after the year in question, using the number of years apart as the weights (i.e., a linear interpolation). Mathematically, using the years of 1970 and 1980 as an example, the costs for 1973 would be approximated by

$$c_{1973} = \frac{(1980 - 1973)c_{1970}}{(1980 - 1970)} + \frac{(1973 - 1970)c_{1980}}{(1980 - 1970)}, \tag{3.6}$$

which simplifies to

$$c_{1973} = 0.7c_{1970} + 0.3c_{1980}. \tag{3.7}$$

Costs for the years between 1960 and 1968 were approximated from the 1969 data adjusted for inflation using the index of prices paid by farmers. Costs for 1989 and 1990 were constructed in a similar manner using the 1988 crop budget figures.

A series of variable costs for each year was also constructed from the Extension cost budgets and the index of prices paid by farmers. Variable costs (orchard upkeep, harvesting costs, etc.) are assumed to begin in the orchard's fourth year as a small crop is generally harvested in that year.

The expected cost series for an acre of almonds planted today therefore consists of establishment costs for the first 4 years and expected variable costs for years 5–35 (i.e., from year 5 until the removal of the orchard, assumed here to be done after 35 years). Establishment costs, including all necessary costs such as irrigation system installation, pruning, water, and chemical applications, are assumed to be known exactly at the time of planting. Variable costs are not assumed to be known at planting. Instead, expected variable costs for each future year are assumed to be equal to the variable costs for existing orchards at the time of planting adjusted upward by an expected rate of inflation for costs. Thus, variable costs s years after planting would be expected to equal

$$vc_{t+s}^{e} = vc_t \left(1 + g_c^e\right)^s, \tag{3.8}$$

where vc_t are the variable costs in year t, g_c is the expected rate of real growth for almond production costs, and the superscript e indicates "expected value." Note that g_c^e can be equal to zero. Variable costs for the first fully-bearing year are shown in Table C3.2, while the establishment costs for an acre of almonds are shown in Table C3.3.Land prices are not included in the establishment costs because it has been assumed that the land can be resold after the life of the orchard for the same real value as the original purchase price.

The formation of the expected series of costs over the life of the orchard completes the first half of the net present value calculation. Expected revenues must then be estimated to complete the exercise.

Revenues

The calculation of the expected stream of revenues begins by estimating the yield per acre for each year in the orchard's life. This is done utilizing Olson's (1986) estimated yield-age profile for a typical almond orchard and a moving average of past almond yields. Olson (1986) developed the yield profile of an almond orchard's productive life from age 4 (when bearing is assumed to begin) through age 50. This profile is expressed as a fraction of the full, mature yield and is given by the yield factors in Table C3.3. Expected mature yields for an acre of almonds planted in a particular year are estimated using the age profile of the tree stock and an assumption of linear growth in yields.

An age profile for almonds was constructed from the data on annual plantings and removals. It was assumed that removals were distributed across trees of different ages with a fraction $(1/n)$ of the removals being 1-year-old trees, $(2/n)$ of the removals being 2-year-old trees, etc., up to $(35/n)$ of the removals being 35-year-old trees (where $n = 1 + 2 + \cdots + 35 = 530$). This divides the removals so that they are concentrated in older trees as would be expected. The resulting age profile is then adjusted by two further steps. First, any negative numbers are set to zero. Second, the age profile of each year is multiplied by the factor necessary to make the acreage of the trees match the reported bearing acreage for each year. The age profile is only constructed to age 35 because almond trees in modern, improved orchards typically do not last until age 50, which was the maximum age considered by Olson.

To estimate expected mature yields the production function was specified as

$$Q_t = A_{4,t}y_{4,t} + A_{5,t}y_{5,t} + \cdots + A_{35,t}y_{35,t} + \epsilon_t, \tag{3.9}$$

where $A_{s,t}$ is the number of bearing acres of age s trees in year t and $y_{s,t}$ is the yield of age s trees in year t. Yields are assumed to follow the relation

$$y_{s,t} = f_s\left(\beta_0 + \beta_1 T_t\right), \tag{3.10}$$

where f_s is Olson's yield factor for age s trees and T_t is a time trend which equals 0 for trees planted in 1960, 1 for 1961 plantings, etc. Thus, 0 is the expected mature yield for trees planted in 1960 and 1 represents the average annual impact of technological improvements on mature yields. Ordinary least squares estimates of the β_i's result in an estimated mature yield for 1960 plantings of 1746 lb/acre (in-shell) with an expected increase of 14.12 lb/acre each year. These expected (mature) yields are also shown in Table C3.3, for 1961–1990. The estimated equation is

$$y_{s,t} = f_s\left(1746.0 + 14.12T_t\right). \tag{3.11}$$

The expected yield (pounds per acre, kernel-weight) of an s-year-old orchard planted in year t is given by the product of the yield factor for s-year-old trees and the expected yield for year t. For example, a 7-year-old tree planted in 1975 would have an expected yield of

$$(0.833) \times (1746.0 + (14.12 \times 15)) = 1631.5 \text{ lbs/acre}.$$

To calculate the expected revenues in a given year, all that is needed is an expected price with which to multiply the expected yield. The real price of almonds forecast by a potential almond investor is assumed to be the most recent real price available: the price in the year immediately preceding planting of the orchard. However, the net present value calculation performed also allowed for the investor to assume that prices will grow at some constant growth rate, g_p. Thus, if we denote the expected price by p_t^e, the expected mature yield as Y_t^e, and the yield factor for trees of age s by f_s, we can write the expected gross revenue in year $t+s$ from an acre planted in year t as

$$RV_{t+s}^e = p_{t-1}\left(1 + g_p\right)^s \left(f_s Y_t^e\right), \tag{3.12}$$

In calculating expected gross revenue in this fashion, a cobweb model is assumed, which seems to require that investors hold the naive expectation that future prices will be equal to the previous year's price. Alternative specifications might involve taking the average of several previous years' prices, or using the predicted price from a full supply-and-demand model of the industry. Later in the chapter, the results of an estimation using several lags of per-acre profitability are reported, which approximates the first alternative strategy. The second approach is really not practical, since the large variations in industry supplies over the lifetime of an orchard make extrapolation of a fitted value into the future no more accurate than an extrapolation of any other value.

After-Tax Net Present Values

To combine all the expected costs and revenues into a single expected net present value of an acre of almonds, the tax impacts of the costs and revenues must be considered. First, all net revenues (revenues minus costs) should be adjusted to after-tax values. Second, the depreciation allowance for the capital cost of establishing the orchard must be calculated and a tax deduction credited to the investor for each year in which the orchard is amortized. Third, in years with an investment tax credit (1961–1985, except for 1967 and 1970), the investor should receive a credit equal to the total establishment cost of the orchard multiplied by the investment tax credit rate (e.g., 10 percent).

This procedure is most easily described in two steps. First, expected net revenues (ENR_t), after taxes, are calculated for each year after bearing begins by subtracting expected variable costs from expected revenues and then applying the income tax to that total (including an allowance for normal depreciation deduction). The second step is to deduct establishment costs and the investment tax credit to create the after-tax, expected net present value ($ENPV_t$). Let MTR_t be the investor's marginal tax rate at the time of planting,[19] ITC_t be the investment tax credit rate (7 percent, 10 percent, etc.), EC_t be the establishment cost (not including land prices), δ_t be the depreciation allowance in year t, and r_t be the real discount rate (opportunity cost of money). Calculate expected net revenues first

$$\begin{aligned} ENR_{t+s} &= \left(RV^e_{t+s} - vc^e_{t+s}\right)(1 - MTR_t) + MTR_t\delta_t \qquad (3.13) \\ &= \left[p_{t-1}\left(1+g_p\right)^s\left(f_sT^e_t\right) - vc_t\left(1+g_c\right)^s\right](1 - MTR_t) + MTR_t\delta_t, \end{aligned}$$

for $s = 4, 5, 6, \ldots, 35$ years from planting. The depreciation allowances are based on straightline depreciation with the capital cost amortized over from 5 to 30 years depending on the tax laws in force at that particular time.[20] Depreciation horizons, marginal tax rates, and investment tax credit rates for the years 1961–1990 are displayed in Table C3.2. Marginal tax rates are constructed as MTR = (the sum of the top federal and California tax rates)/2 + the self-employed social security tax rate. Thus, the tax rate used represents an average between the top marginal rates and the bottom marginal rates (which are zero). This rate should be fairly robust as investors in higher marginal tax brackets are more likely to exceed the social security cap, tending to bring their total marginal rate back in line with the ones used here.

The expected net present value of a newly planted acre of almonds is then given by

$$\begin{aligned} ENPV_t &= -\sum_{s=1}^{B} EC_{t+s-1}(1+r_t)^{1-s} + \sum_{s=4}^{35} ENR_{t+s}(1+r_t)^{-s} \qquad (3.14) \\ &\quad + ITC_t(1+r_t)^{-B}\sum_{s=0}^{B} EC_{t+s}, \end{aligned}$$

where the variables are as defined above. Note that the investment tax credit is applied to the entire capital cost of establishing the orchard, and is declared in year $t + B$, while the establishment costs themselves are discounted on an annual basis to properly account for the impact on cash flow of the actual cash disbursements.[21]

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[19] It is assumed that the investor expects that current tax rates will hold in the future.

[20] Note that the actual (economic) depreciation is subsumed in the yield function and in the expectation that the orchard will be removed 35 years after planting; tax depreciation then enters the present-value calculation as a tax benefit to the investor.

[21] Note that orchard costs in years $t + 4, \ldots, t + B$ are included in the calculation of $ENR_t + s$, hence do not appear in the first term of 3.14, but are also included in the computation of the investment tax credit (the last term of 3.14).

The number B in the summations accounts for the fact that in the 1960s and 1970s, almond orchards were not considered of bearing age for the first 5 years following planting, so that establishment costs continue for 5 years, while in more recent years, the orchard is deemed fully established and bearing after 4 years. Thus, B is either 4 or 5 years from planting.

Values for the expected net present value of an acre of almonds were calculated as described above for the years 1961–1990 using discount rates derived from data on the real after tax opportunity cost of funds. The interest rate on long term (30 year) bonds is multiplied by $(1 - MTR_t)$ to compute the after tax return, then an expected rate of inflation is subtracted to yield an expected, real, after-tax rate of return. This series is used as the discount rate even in years when it is negative, such as during times of high inflation. The expected inflation rate is taken to be a four year, weighted moving average of the percentage increase in the GNP deflator, where the weights are .4, .3, .2, and .1 on the past four years' inflation rates. The values of $ENPV$ in each year were then converted to constant (1977) dollars using the GNP deflator. For example, during 1967, 1968, 1969 and 1970, the percentage increases over the previous year in the values of the GNP deflator were, respectively, 3.55, 2.57, 5.01, and 5.57, so that the expected inflation rate in 1970 was

$$(0.1)(3.55) + (0.2)(2.57) + (0.3)(5.01) + (0.4)(5.57) = 4.60 \text{ percent.}$$

The nominal interest rate was 6.51 percent, and the marginal tax rate was 47.5 percent, so the expected real after-tax discount rate is $(6.51)(1 - 0.475) - 4.60 = -1.18$ percent, which was then applied to the various expected cost, net revenue, and tax terms as shown in (3.14).

3.6 Estimation of Models

The plantings and removals models specified above were estimated using the data series as developed and described.

Plantings Model—Traditional

The TM (traditional plantings) model presented above was estimated by OLS using data for the 1962–1990 period. Net after-tax returns were calculated as (price × yield – variable cost)(1 – marginal tax rate) using the marginal tax rate assumptions described in Section 3.5. These profitability measures were then transformed to real terms (1977 dollars) using the GNP deflator.

The TM plantings equation was estimated with the variables as specified above and with the same variables plus a time trend. Both forms were also estimated with the dependent variable specified as PL_t/TA_t (plantings/total acreage) but these results are not reported since they were inferior to the models using plantings as the dependent variable.[22] The estimated TM plantings regression equation including the time trend, with associated statistics, is

$$\begin{aligned} PL_t \;=\; & \underset{[t=-1.50]}{-11387.0} + \underset{[t=3.50]}{35.259\,\pi_{t-1}} + \underset{[t=2.36]}{25.988\,\pi_{t-2}} \\ & + \underset{[t=3.11]}{0.17750\,K_{t-1}} - \underset{[t=-1.20]}{0.49056\,R_t} - \underset{[t=-2.79]}{2029.0\,T_t} \\ & R^2_{adj.} = 0.59 \qquad D.W. = 1.32 \end{aligned} \tag{3.15}$$

where PL_t is plantings in acres, in year t, π_t is state-average net after-tax returns

[22] A number of alternative specifications were investigated, including the specifications adopted by French and King (1988). None of the alternative specifications performed as well as the model reported here.

per acre, in constant 1977 dollars, K_t is acreage in year t, R_t is removals in acres in year t, and T_t is a time trend, 1962=1.[23]

The explanatory power of the TM plantings equations (as measured by $R^2_{adj.}$) is acceptable but not as high as one would prefer. This is probably more a reflection of the quality of the data than the model specification. The Durbin-Watson ($D.W.$) statistic is acceptable.

In the estimated TM plantings equation, farmers' expectations of future profits seem to be formed mainly by the two most recent years' net returns. The capital stock has a small, significant, and positive effect on investment, possibly reflecting a trend in demand or a demand for replacement investment (for anticipated future removals). The most curious result is the negative coefficient on removals; this coefficient would be expected to be positive and in the neighborhood of one. One explanation is that this variable is picking up a missed factor in profit expectations; that is, large removals in the immediate past period are correlated with reduced expected future returns.

Plantings Model—ENPV

Partial adjustment ENPV planting equations using both current period and one-year lags of $ENPV_t$ were estimated using OLS. The $R^2_{adj.}$ increased from approximately 0.60 using the current period, $ENPV_t$, to 0.76 when variable was lagged one period ($ENPV_{t-1}$). The specification with the lagged variable is clearly superior; the estimated equation is:

$$PL_t = \underset{[t=1.92]}{3.2120} + \underset{[t=5.58]}{0.00058\, ENPV_{t-1}} + \underset{[t=6.08]}{0.5810\, PL_{t-1}} \qquad (3.16)$$

$$R^2_{adj.} = 0.76 \qquad h = 1.18$$

where PL_t is plantings (thousands of acres) in year t and $ENPV_t$ is the expected net present value of an acre of almonds planted in year t, in 1977 dollars. Durbin's h statistic is not significantly different from zero, indicating no autocorrelation of the regression residuals. The signs on the estimated coefficients are positive, as expected, and both are statistically significant.[24]

Removals Model—Traditional

The traditional removals model was estimated using OLS with data for the period 1962 through 1990. The estimated removals equation is:

$$\begin{aligned} R_t = {} & \underset{[t=1.56]}{5398.8} - \underset{[t=-1.05]}{5.184\,\pi_{t-1}} - \underset{[t=-1.63]}{7.8458\,\pi_{t-2}} - \underset{[t=-2.62]}{13.831\,\pi_{t-3}} \qquad (3.17) \\ & - \underset{[t=-0.62]}{2.8431\,\pi_{t-4}} + \underset{[t=0.16]}{0.0044\,K_{t-1}} - \underset{[t=-0.92]}{2335.6\,D70_t} + \underset{[t=0.57]}{28.375\,D76_t} \\ & + \underset{[t=0.10]}{738.4\,D82_t} \end{aligned}$$

$$R^2_{adj.} = 0.59 \qquad D.W. = 2.21$$

where R_t is the number of acres removed in year t, K_t is year t bearing acreage, π_t is year t state-average after-tax return per acre, in 1977 dollars, and three 0–1

[23] Since the coefficients describing the effects of per-acre returns, lagged three and four years, were insignificant, they ewere excluded from the eeported equation.

[24] In addition to this plantings model, a model using net investment, plantings less removals, as the dependent variable was also estimated. This model also incorporated a partial-adjustment mechanism. While the variables had the expected signs, Durbin's h-statistic indicated significant autocorrelation. This model was not pursued further.

dummies to account for changes in tax laws are $D70_t = 1$ for 1970–1975, $D76_t = 1$ for 1976–1981, and $D82_t = 1$ for 1982–1990. While each of the coefficients on the lagged profitability variables each has the expected negative sign, only one of the four has a significant t-value. The coefficient on the stock of trees (K_{t-1}) also has an expected positive sign but is not significant. The three tax dummy variables included were not significant.

Removals Model—ENPV

The ENPV removals model was also estimated using OLS methods for the period 1962 through 1990. The estimated equation is

$$R_t = \underset{[t=-1.99]}{-5.248} - \underset{[t=-0.71]}{0.000052\, ENPV_{t-1}} + \underset{[t=3.85]}{0.1370\, PL_{t-1}} \qquad (3.18)$$

$$R^2_{adj.} = 0.38 \qquad D.W. = 1.23$$

where R_t and $ENPV_t$ are as previously defined and OLD_t is the acreage of trees over 20 years old and bearing in year t. While the coefficients on the two variables have the expected signs, only the acreage of trees over 20 years of age (OLD_{t-1}) is significant. The explanatory power of the ENPV removals model is low, both in absolute terms and relative to the traditional removals model. There are several possible reasons for unexplained variation in the removals relationships. First, the quality of removals data is typically suspect and the accuracy of the almond removal data is easily questioned. Second, the better performance of the traditional model could be due to removals being driven by short-term market conditions such as recent profitability or prices of almonds.[25] Third, the almond tree age variable (that uses an age of 20 years based on data availability) is probably too low since most available information indicates that removals due to age often occur after 30 years of age. Finally, almond growers may wait beyond what appears to be the optimal removal time in order to improve their estimates of future profitability while avoiding sunk exit/entry costs (see Dixit (1989) for a description of such investment models). Overall, there are good reasons to believe that the ENPV formulation is a misspecification of the removals problem; these considerations reinforce the statistical evidence, which favors use of the TM model for removals.

3.7 Validation of Models

From a statistical standpoint, the best plantings equation is a partial-adjustment model using lagged expected net present values, equation (3.16). This equation is used in the within-sample simulation model of Chapter 6, and in that model's application in a revenue-maximization setting, in Chapter 7. The fitted values from this regression are plotted along with actual values in Figure 3.2. Our preferred removals equation is the traditional model, equation (3.17). Actual removals and the fitted values from (3.17) are plotted in Figure 3.3.

Formal validation of these two equations includes the analysis of statistics describing the fit of the equations over the estimation period and the evaluation of the strength of the equations at forecasting out-of-sample data. Pindyck and Rubinfeld (1981) have shown that even equations with high goodness-of-fit coefficients, significant t-values, and good Durbin-Watson statistics may not forecast well within the estimation period. In addition, if the equations are to be used for forecasting, it is useful to evaluate out-of-sample performance. Having in mind this evaluation, we reserved data for 1991 and 1992 for out-of-sample validation.

[25] French and King (1988), Nuckton, French and King (1988), and French and Willett (1989) concluded that removals are dominated by age (productivity) factors and vary with return factors only in the short run.

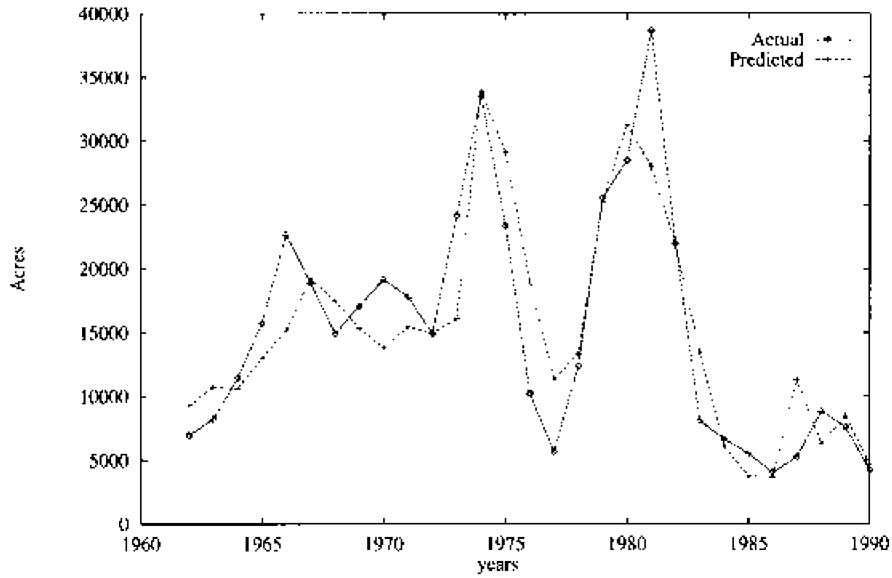


Figure 3.2: Plantings of California Almond Acreage, Actual and Predicted

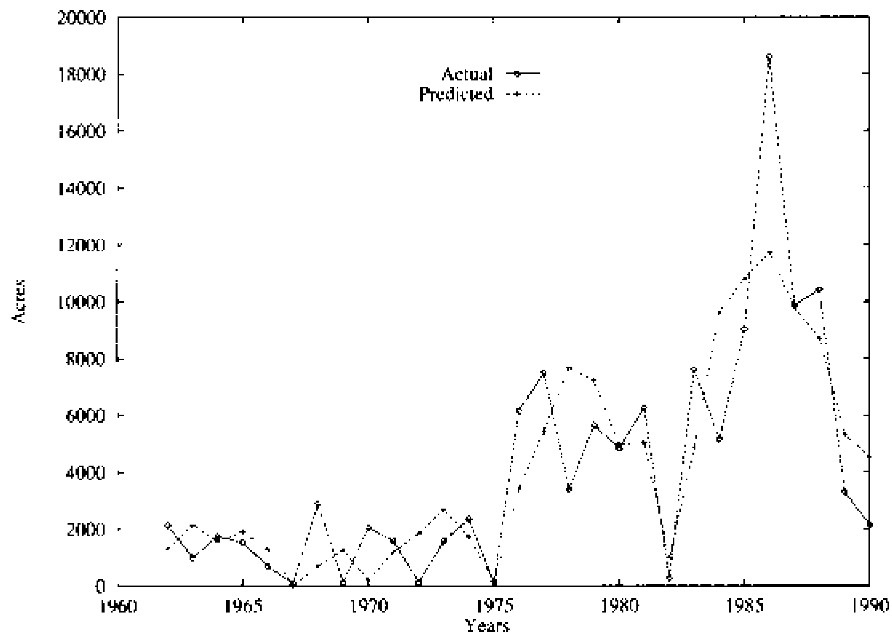


Figure 3.3: Removals of California Almond Acreage, Actual and Predicted

Table 3.2: Validation Statistics for Plantings and Removals Models

Country	*Estimation Period*	*RMSE*	*TIE*	U^B	U^V	U^C
Within-sample:						
Plantings	1961–90	4.273	0.023	0.000	0.065	0.935
Removals	1962–90	2.209	0.037	0.000	0.089	0.911
Out-of-sample:						
Plantings	1991–92	1.920	0.280			
Removals	1991–92	2.061	0.434			

Notes: *RMSE* is Root Mean Square Error. *TIE* is the Theil Inequality Coefficient, a normalization of *RMSE*. U^B, U^V, and U^C are, respectively, the bias, variance, and covariance components of *RMSE*. Both equations are linear. Since the *RMSE* decomposition is not well defined for two or less observations, it is omitted for the out-of-sample exercise.

For both the within-sample and the out-of-sample validation, we calculated the Theil Inequality coefficient (*TIE*), defined for actual values a_t and predicted values p_t as

$$TIE = \frac{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(p_t - a_t)^2}}{\sqrt{\frac{1}{T}\sum_{t=1}^{T}p_t^2} + \sqrt{\frac{1}{T}\sum_{t=1}^{T}a_t^2}} \qquad (3.19)$$

Note that the numerator of *TIE* is the square root of the Mean Square Error,

$$MSE = \frac{1}{T}\sum_{t=1}^{T}(p_t - a_t)^2.$$

The *TIE* is a scaling of the root mean square error, so that $TIE = 0$ implies that the predicted and actual values are identical, while if the predictions are uncorrelated with the observations, then $TIE = 1$. In addition to this scaling, the mean square error can be broken down into proportions of inequality,

$$U^B = \frac{(\bar{p} - \bar{a})^2}{MSE},\ U^V = \frac{(s_p - s_a)^2}{MSE},\ U^C = \frac{2(1 - \rho_{pa})a_p a_a}{MSE},$$

where s_p and s_a are the standard deviations of p and a, respectively, and ρ_{pa} is the correlation coefficient between p and a. These proportions are described as the bias, variance, and covariance proportions of the simulation or forecast error: U^B measures the difference in the means of the predicted and actual series, U^V measures the difference in the variability of the two series, while U^C measures the degree to which the two series move together. Noting that

$$U^B + U^V + U^C = 1,$$

it is desirable if *TIE*, U^B, and U^V are small, and U^C is close to 1. The validation statistics for the preferred planting and removal models are listed in Table 3.2.

Within-sample, the two models perform very well, with *TIE* close to zero, $U^B = 0$ (this is true for all OLS estimates), with U^V low and U^C high. The plots of actual and predicted values illustrate the good overall fit, with a good correspondence between turning-points, as indicated by the covariance proportion U^C.

Out of sample, the plantings model continues to perform fairly well, *TIE* below 0.3 (which Pindyck and Rubinfeld (1981) describe as "small," and with most of the "error" found in the unsystematic covariance proportion. The performance of the removals model is somewhat weaker, with relatively high *TIE*, and with most of the error due an inability to match the variability of actual removals (U^V is large, while U^C is small).

4. SPANISH ALMOND PRODUCTION

4.1 Introduction

World almond production has changed considerably since 1950. In the early 1950's, Italy was the world's major almond exporter and the United States imported from 7 to 22 percent of its annual supply of almonds. The United States, with growing almond production, became a net exporter in 1959 and U.S. exports have trended up since then. Over the past 25 years California has become the world's dominant producer and exporter of almonds, followed by Spain with its large almond plantings and growing production. As almond production expanded in California and Spain, Italy's production decreased, a change attributable in part to the growth in labor costs that has accompanied Italian economic development (Bushnell 1978). Italy now imports almonds. For the three marketing years 1989–90 through 1991-92, California accounted for an average of 66.3 percent, and Spain an average of 17.1 percent, of world almond production. California and Spain accounted for 96 percent of world exports: 80.1 percent for California and 15.9 percent for Spain.

Spanish almonds compete closely with California almonds in export markets, resulting in highly correlated prices. Thus, actions by the California industry that affect the price of almonds in export markets will have an impact on the Spanish almond industry and vice-versa. Because Spain is an important competitor, and the response of Spanish producers to changing prices is important to the California industry, we attempt to model the Spanish industry.

Spanish almond acreage grew steadily during the 1960s and then expanded dramatically during the 1970s. Spain had a total of 438,900 acres of almonds in 1959. As shown in Figure 4.1, this amount grew to 735,100 acres in 1970, then almost doubled to 1,394,900 acres in 1980, expanding to 1,517,500 acres in 1989. Of the 1989 total, 1,437,700 acres were bearing, with the remaining 79,800 acres nonbear-

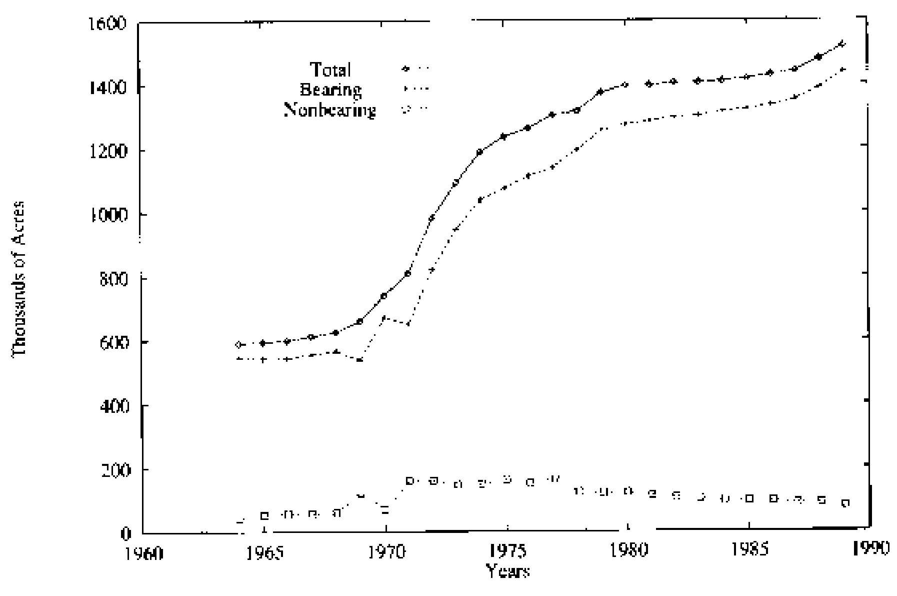


Figure 4.1: Total, Bearing, and Nonbearing Spanish Almond Acreage

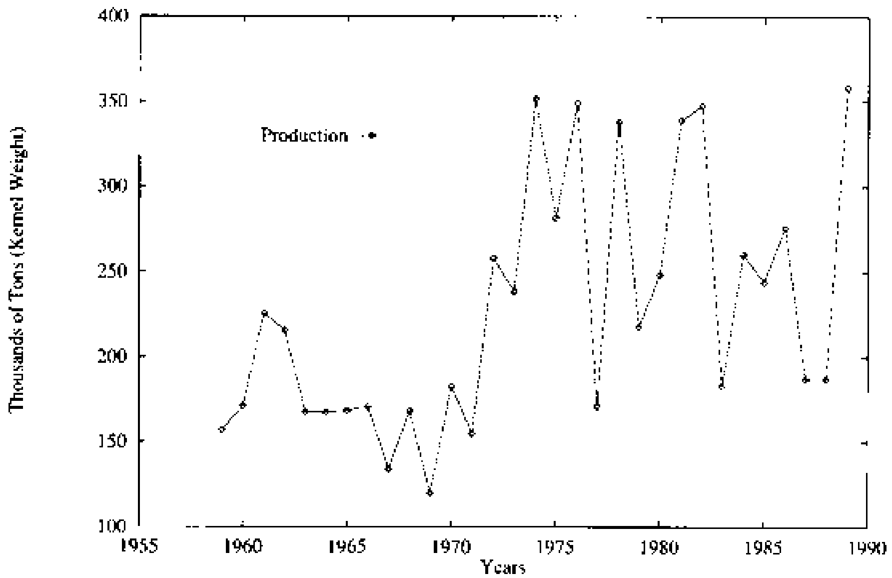


Figure 4.2: Spanish Production of Almonds

ing. The only recorded decrease in total area occurred between 1989 and 1990 with a 700 acre reduction to 1,516,800 acres.[1] While the area devoted to almonds in Spain is much larger than in California (1.517 million acres vs. 432,000 acres in 1990), California has larger annual production. Only 111,900 acres (7 percent) of Spanish almonds are irrigated, and average yields for non-irrigated almonds are low. Detailed data on Spanish acreage and production are in Table C4.2 in the Appendix.

The substantial increases in Spanish almond acreage have been partially offset by reductions in average yields. In Figure 4.2 total Spanish almond production was 157,000 tons in-shell in 1959, and increased to as high as 351,300 tons in 1974 on 1,037,800 bearing acres.[2] With increased plantings, total production peaked in 1989 at 358,100 tons on 1,437,700 acres.

Average Spanish almond yields per bearing acre for the period 1959 through 1989 are shown in Figure 4.3. Overall yields have varied from a high of 633 pounds in-shell per acre in 1961 to a low of 259 pounds per acre in 1988. Separate yield data for irrigated and non-irrigated almonds are available for 1971 through 1989. As shown in Figure 4.3, irrigated yields are usually almost three times as large as dry-land yields. For the 19 years shown, average irrigated yields were over 1,000 pounds per acre (in-shell) during 12 years, with the highest yield being 1,434 pounds per acre in 1989. As a basis for comparison, during the same time frame California's lowest average yield was 1,000 pounds per acre (in-shell) in 1978 and the highest yield was 2,680 pounds per acre in 1987. The downward trend in Spain's overall

[1] Note that 1990 data are not included in figures 4.1 and 4.3 since only total production and total acreage data were available.

[2] Total production reported in Spanish statistics includes estimated production from scattered trees (single trees that are not part of an organized almond enterprise and typically receive little care). These trees, which are not included in the acreage statistics, are estimated to typically account for about 10 percent of total production. Because of this, multiplying bearing acreage by average yield will result in total production that does not include production from scattered trees, and as a result is less than total reported production.

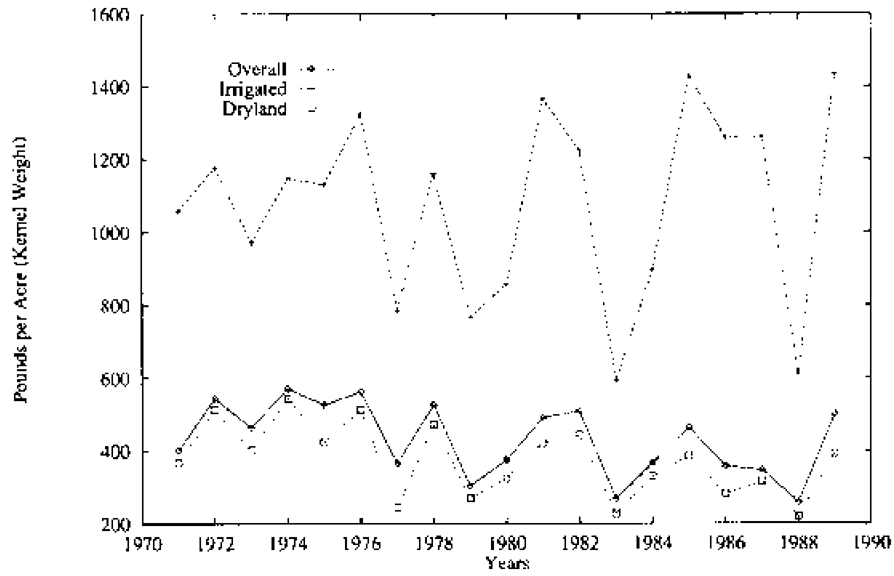


Figure 4.3: Yields of Spanish Almonds, Dry-land, Irrigated, and Overall

average yields is in line with a downward trend in dry-land yields. This downward trend could be due to several factors, including expansion on marginal lands or the changing age distribution of trees.

4.2 Spanish Almond Acreage Response

The model of short-run and long-run acreage adjustments in the Spanish almond industry follows the general format of the model of the California industry, as presented in Chapters 2 and 3. There are, however, data limitations that require some modification of the estimated supply response equations. These limitations include (*i*) a shorter data series extending from 1959, from 1964, or from 1971 through 1990, depending on variables, (*ii*) no data on either new plantings or removals, and (*iii*) some apparent changes in sampling and reporting over time.

Yield Model

The almond yield model for California, discussed and developed in Chapter 2, is easily adapted to Spain. Differences in production methods must be considered in model adaptation. A large proportion of plantings in Spain are on unirrigated land. One would therefore expect weather conditions (especially rainfall) during the growing season to be a more important determinant of dry-land yields than one would find under irrigation. With the data available, separate yield equations for dry land and irrigated land can be estimated for the period 1972 through 1989. The data used in these estimations are listed in Table C4.1.

The preferred yield model for California almonds, estimated in Chapter 2, can be adapted to the Spanish situation with the following specification:

$$y_t = f\left(y_{t-1}, y_{t-1} - y_{t-2}, T_t, YB_t/B_t, FF_t, JFR_t, MAR_t, JR_t\right), \qquad (4.1)$$

where, in year t, y_t is average yield per bearing acre, T_t is a trend variable, YB_t/B_t

Table 4.1: Regression Models of Spanish Almond Yields

Dep. Var.	y_{t-1}	T_t	JFR_t	FF_t	MAR_t	JR_t	Constant	e_{t-1}	
y_t^{Irr}	-0.3963	33.84	-4.605	-166.3	2.694	19.78	1633	-	$R^2_{adj} = 0.42$
[t]	[-1.74]	[2.39]	[-2.23]	[-2.25]	[1.37]	[2.45]	[3.90]		$m = -1.52$
y_t^{Dry}	-0.3015	-8.062	-1.179	-26.24	1.395	1.937	630.8	-0.786	$R^2_{adj} = 0.89$
[t]	[-2.67]	[-4.82]	[-5.59]	[-3.66]	[6.93]	[2.26]	[9.48]	[-5.02]	$h = -1.53$
y_t^{Tot}	-0.1819	-4.145	-1.487	-45.70	1.379	2.026	672.2	-0.912	$R^2_{adj} = 0.92$
[t]	[-2.38]	[-3.20]	[-8.58]	[-7.65]	[8.31]	[2.82]	[12.8]	[-9.29]	$h = -0.73$

Notes: Values in brackets are t-ratios. Dependent variables are yields (kilograms per acre) for irrigated acreage (y_t^{Irr}), dry acreage (y_t^{Dry}) and total acreage (y_t^{Tot}). For each equation, y_{t-1} is the lagged dependent variable, T_t is a linear time trend ($T_{72} = 1$). JFR_t is the average rainfall (in millimeters) during January and February across each of the 7 provinces of Levant and Andalusia, FF_t is the average number of frost days during February in each of the Levant and Andalusia provinces. MAR_t is average rainfall during March and April, and JR_t is average rainfall during July. For the "Dry" and "Total" equations, e_{t-1} is the lagged error in a Cochrane-Orcutt interative estimation, and h is Durbin's h statistic following the autoregressive estimation. For the "Irrigated" equation, Durbin's m is reported, indicating no significant autocorrelation.

is the proportion of bearing area that is 5 to 9 years old, FF_t is February frost, JFR_t is January and February rainfall, MAR_t is March and April rainfall, and JR_t is July rainfall.

The variables used in the analysis are defined as follows. The average yield is measured as kilograms per bearing acre (in-shell). Spanish data on the age distribution of almond trees are not available, but nonbearing acreage advanced five years provides a measure of young bearing acreage, assuming that there are no removals from that age group during the five year period. Spanish almond production is influenced by both rainfall and frost. Rainfall during January and February affects pollination, thus we expect increased rainfall during these months to be associated with decreased average yields. Rainfall during the growing season is also important and increased rainfall during the critical months of March, April and July is expected to be associated with increased average yields. Frost during February can have an adverse impact on yields. The rainfall and frost variables were measured for the two major production regions, Levant and Andalusia. Monthly rainfall is measured in millimeters and is a simple average of the rainfall in each of the seven provinces in the two regions. The frost variable is also a simple average (over provinces) of the number of frost days in February in the two regions.

Results of estimating the average yield equations were in line with expectations and most of the variables were statistically significant with correct signs. However, the second lagged yield variable ($y_{t-1} - y_{t-2}$) was insignificant in each of the equations and was dropped. The proxy variable used to measure the proportion of new bearing area (YB_t/B_t) was also insignificant in each of the equations and was dropped. The results for each equation are shown in Table 4.1.

There was a downward trend in aggregate and dry-land yields, while irrigated yields increased. Rainfall and frost had the hypothesized sign in each equation, although not all coefficients were significant. The individual equations explain a respectable percentage of the annual variation in average yields as measured by R^2. In the equation for yield on irrigated acreage, Durbin's m statistic is insignificant, suggesting that autoregressive errors are not a problem. However, in the equations for yield on unirrigated acreage and on all land, there is evidence of autocorrelated residuals with OLS regression. These equations were therefore estimated using the Cochrane-Orcutt procedure. The Durbin h statistic is reported, indicating no higher-order autoregression in these equations.

Net Investment Models

The significant expansion of total area devoted to almond production in Spain is shown in Figure 4.1. As noted, almond area increased about 740,000 acres during the 1970s, an expansion that exceeds California's total almond acreage. Two factors appear to be associated with the rapid increase in almond acreage during the 1970s. First, it was a period during which producers enjoyed favorable returns and, second, the Spanish government was providing subsidies to encourage expansion of agricultural production (including almonds). Spanish government support of almond development included several important features. Beginning in 1970, new growers became eligible for low interest rate loans and a subsidy of up to 20 percent of the cost of permanent improvements in land and facilities. The government also provided assistance for procurement of inputs and improvement of production techniques (Gardiner and Lee 1979). Government policy to expand Spanish almond production was effective for the period 1970 through 1977, but appeared to influence net investment through 1979.

As noted in Chapter 3, new plantings and removals decisions are the major investment decision made by the producers. Data on Spain's total almond area are available, but new plantings and removals are not reported. Net investment (N_t), the difference between new plantings and removals, can be calculated from total area data. As noted in Chapter 3,

$$A_t = A_{t-1} + PL_t - R_t, \tag{4.2}$$

which can be expressed as

$$A_t - A_{t-1} = PL_t - R_t = N_t,$$

where A_t = total area (acres) planted to almonds in year t, N_t = net investment (i.e., the change in total area), PL_t = new plantings of almonds and R_t = removals of almonds.

Total acreage of almonds is a proxy for the capital stock if planting density does not change over time and does not vary from region to region. Net investment, based on the change in total almond acreage from one year to the next, is modeled similarly to the area response models developed for Spanish oranges and mandarins by Albisu and Blandford (1983). It is also similar to the acreage response model for Spanish almonds in Bushnell (1978), although it includes data for all farm costs, including land, which should capture the effects of changing returns from other crops, indicated in Bushnell by the farm price of oranges. The net investment function for Spanish almonds is specified as:

$$N_t = f\left(P_t, C_t, Support, Age\ Distribution\right), \tag{4.3}$$

where net investment is a function of expected profits from almond production (i.e., as represented by prices and costs), government support policies and the age distribution of almond trees. The rationale for this model specification is similar to that used for models previously reviewed, with the choices of particular explanatory variables based on data availability.

Farmers' planting decisions are assumed to be based on expected profitability: a function of expected prices, expected yields, production costs, government programs and policies, and the profitability of alternative crops. Most Spanish almond orchards have been located on marginal lands in arid areas where crop alternatives are limited (Caballero, Miguel, and Julia 1992). Other nuts, such as filberts, are produced only in Tarragona, a province of the Catalonia region. Specification of variables to represent the profitability of alternative crops was not attempted.

Spanish almond yields vary significantly from year to year (Figure 4.3) due to alternate bearing tendencies and weather conditions. Since most Spanish almonds are grown without irrigation, yields are very sensitive to weather conditions, especially frosts and rainfall during the blooming and growing seasons, respectively. Since farmers are presumably familiar with yield variability, an attempt was made to combine information on prices with information on yields to form a measure of expected profitability. This effort was unsuccessful: the simple average of past prices was a better predictor of net investment decisions.[3] Note that average yields have been approximately constant, so that expectations regarding yields can be treated as a constant when modelling the formation of expectations regarding profitability.

Expectations regarding profitability appear to have been based on recent experience. Various averages of prices deflated by a cost index were tried as proxies for expected profits. A simple two-year average of prices deflated by the cost index, lagged one and two years, provided the best statistical results. This variable can be expressed as

$$AP_t = \frac{P_{t-1} + P_{t-2}}{2}. \tag{4.4}$$

The age of the capital stock (the age distribution of trees) is expected to affect investment decisions. If the age distribution of the existing orchards is relatively young, then one would expect there to be a decreased incentive for net investment in new orchards. On the other hand, if the existing capital stock is very mature, one would expect to see both plantings and removals to be greater for given prices and costs. The impact on net investment is uncertain. Spanish almond statistics identify trees as bearing five years after planting. It appears that their productive decline starts when they are about 35 years old. To account for this, the acreage of trees older than 34 year is measured as OB_t.

Government subsidies and planting incentives increase the profitability of almond production relative to other activities and increase net investment, *ceteris paribus*. A zero-one dummy variable, which assumes a value of one for the years 1969 through 1979 (except 1972), captures the effect of the government program to expand almond production. Due to the extremely high increase in new plantings in 1972, we included a dummy variable for this year.

The model of annual net changes in Spanish almond acreage was estimated for the period 1965 through 1989 using the data in Table C4.2. The preferred model included variables to measure the impact of revenues, costs, government planting subsidies, and the acreage of old-bearing trees. The estimated equation is

$$\begin{aligned} N_t \;=\; & \underset{[t=-4.39]}{-161.39} + \underset{[t=3.02]}{0.448\,AP_t} + \underset{[t=5.33]}{43.63\,SUB_t} \\ & + \underset{[t=16.97]}{145.8\,D72_t} + \underset{[t=4.06]}{0.29\,OB_{t-1}} \end{aligned} \tag{4.5}$$

$$R^2_{adj.} = 0.80 \qquad D.W. = 1.88$$

where N_t is the net annual change in Spanish almond acreage, in thousands of hectares (total acreage in year t minus total acreage in year $t-1$), AP_t is the expected profitability of almonds (dollars per metric ton) based on a simple average of prices deflated by the General Farm Cost Index, 1985=100, (published by Spanish Department of Agriculture) for years $t-1$ and $t-2$, SUB_t is a zero-one variable to

[3]As noted in Chapter 3, most prior studies have used either prices or total revenue as proxy measures for expected profits. Both measures were evaluated for the Spanish investment model, with the price variable providing the best statistical results. Note that this is different from the present value model used for California supply response.

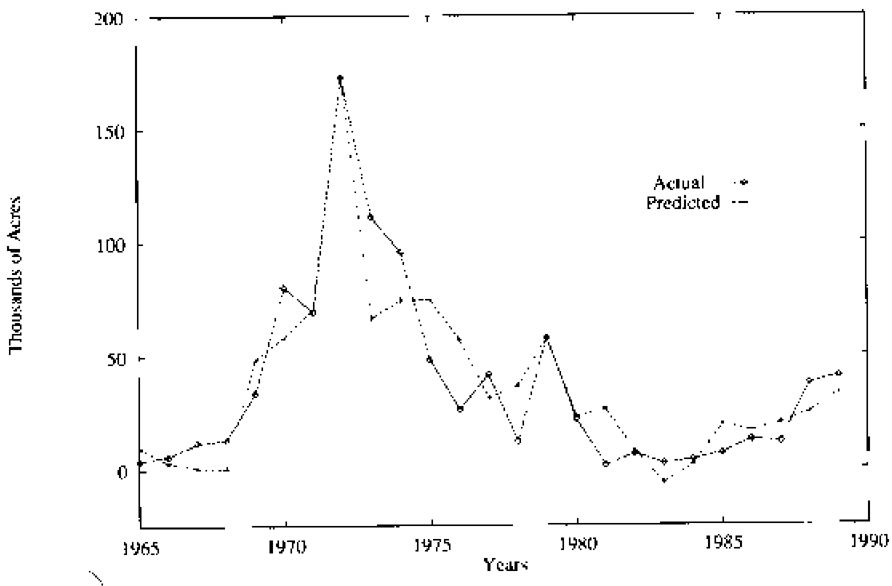


Figure 4.4: Actual and Predicted Changes in Total Spanish Almond Acreage

measure the impact of Government planting subsidies (assumes a value of one for the years 1969 through 1979, except for 1972), $D72_t$ is a zero-one dummy variable to account for unusually high new plantings in 1972, OB_{t-1} is acres of old bearing trees in year $t-1$ (trees over 34 years old, in thousands of hectares).

These results are generally consistent with expectations in that the coefficients have the predicted signs, are of plausible magnitudes, and are statistically significant. The results are also consistent with the acreage response equation for California. The statistical performance of the model was quite satisfactory as well, with a high proportion of the sample variation being explained by the variables included and there being no evidence of autoregressive residuals. In Figure 4.4, the estimated values for net investment from the model are plotted and compared with actual values.

Spanish almond producers have tended to increase new almond plantings when average prices adjusted for costs increased. They have also tended to increase investment as old almond acreage increased. Spanish producers reacted as expected to government planting/production incentives and subsidies effective during the years 1969 through 1979. The estimated coefficient on the subsidy variable indicates that the annual increase in Spanish acreage was 108,000 acres more during the period 1969 through 1979, when the subsidies were effective, than during other years when subsidies were not available to almond producers. The estimated coefficient on the dummy variable for 1972 indicates that the acreage increased over 360,000 acres more than expected that year. While some 108,000 acres can be explained by government subsidies, no explanation is offered for the other 252,000 acres.

The significant increases in Spanish almond acreage and production that occurred during the 1970's can be largely explained by two factors. First, the period during which Spanish government planting subsidies and supports were effective was associated with an increase of about 175,000 acres. Second, and most important, almond prices were generally favorable over this period and producers responded as expected, by significantly expanding their investment in almond production capacity.

4.3 Forecasting Yields

The estimated average yield equation can be used to develop annual forecasts of Spanish almond yields, in a manner similar to that shown for California in section 2.6. The values for the right-hand side variables used in the yield forecast will depend on timing. If, for example, one was making a forecast of next year's yield for the total area right after the fall harvest, actual data would be available only for lagged yield and time; averages would be required for each of the weather variables. One could then update the forecast as observations became available for each of the variables.

While we can predict an annual change in total Spanish acreage, we do not have an equation to predict bearing acreage. Thus, we are unable to combine expected yields with bearing acreage to forecast total production. Without a working model of production, and without either an accompanying domestic demand model or an estimate of Spanish net exports, one cannot incorporate the work on Spanish acreage response and yields into a full simulation model of the world almond industry. However, the estimated acreage response was used to create a Spanish supply-response function in the long-term policy-optimization model of Chapter 7.

4.4 Conclusion

The short-run response of Spanish almond production to changing yields and the longer-run net response of planted area to economic variables have been modeled. Results are consistent with those for the California industry and estimated relationships appear quite reasonable.

While the area planted to almonds in Spain is much larger than that in California, total production from Spain is smaller because of cultural methods. While almost all California almond production is irrigated, 93 percent of Spanish acreage is unirrigated. Spanish yields are dependent not only on weather during the bloom period, but also on rainfall during the growing season, and as a result yields are quite variable. Average yields have been trending down on dry land and trending up on the small amount of irrigated area.

The net investment model indicates that Spanish almond producers expand plantings (and perhaps reduce removals) when average prices increase and reduce net investment when costs increase. Spanish producers also react in the expected manner to planting/production incentives and subsidies. Thus, actions taken by the California producers to increase almond prices will encourage increased production by its major competitor if higher producer prices are transmitted (as it is expected they will be) to international markets.

5. THE DEMAND FOR ALMONDS IN NATIONAL MARKETS

5.1 Introduction

California is now the dominant producer of almonds in the world. The decisions made by the California almond industry have a major influence on almond prices and supplies in other countries. An understanding of the relationships between almond prices and quantities traded will help the California almond industry to manage its strong position in the world market. This chapter presents estimates of the effects of prices and total consumption expenditures on almond purchases in the United States, Japan, and 12 major European almond-consuming countries.

We begin the chapter with an overview of the international almond market. Sections 5.2 and 5.3 then describe theoretical and econometric considerations relevant to the work, and Section 5.4 discusses the data sources used in the analysis. In Section 5.5, we present the principal estimation results. In Section 5.6 we discuss various econometric issues, including the treatment of prices as exogenous variables in each individual function, and our assumption of a single, integrated almond market in which almonds from California and other sources are close substitutes.

The last twenty five years have been marked by two simultaneous, and related, major developments in the world almond industry. First, the quantity of almonds sold in the world's markets has more than doubled, from about 120,000 tons in 1965, to over 280,000 tons in 1989.[1] The second development is the tremendous growth of the California industry: in 1965 California accounted for under 45,000 tons, or about 37 percent, of the world supply, while by 1989 the California industry produced over 244,000 tons, by itself producing more than twice the 1965 world supplies, and accounting for over 85 percent of the world's traded volume. During this period, the Italian market share steadily disappeared. The world's largest exporter in 1961 is now, in most years, a net importer of almonds, a shrinkage which has been attributed (Bushnell 1978) to increases in labor costs in the traditionally labor-intensive Italian almond industry. The world almond industry has changed from a market with several major suppliers to a larger market dominated by the California industry.

The California almond industry is export oriented. Exports have exceeded domestic sales annually since the 1973/74 crop year. During the 1991/92 crop year, the California industry reported exports of about 169,000 tons, or about 60 percent of the industry's total final sales. Exports have grown faster than domestic sales.[2] If we are to understand the California almond industry, we must have good models of demand in these export markets.

The European Union (EU), especially Germany, has recently become the largest importer of almonds in the world and also the largest export market for California almonds. The most rapid recent growth in almond demand has, however, occurred in the Asian markets, particularly Japan, which is now the second-largest single export market for California almonds. The changing sizes of the various consuming markets was illustrated in Figure 1.1 in Chapter 1. It is worth noting that the

[1] This is calculated as California handler receipts, plus exports by other countries reporting production to the U.N. Food and Agriculture Organization. For example, in 1989 U.S production was about 244 tons, Spanish exports were 29,000 tons, Italian exports were 6,000 tons, and exports by other producers (Turkey, Morocco, Tunisia, Portugal, China and Chile) were 3,000 tons, for a total market size of 282,000 tons. The true market size is somewhat larger than this, as this measure excludes the consumption of domestically produced almonds in the non-U.S. producing countries, for which reliable data are not available.

[2] The domestic market has nonetheless grown steadily, from around 37,500 tons per year in the early 1970s to over 100,000 tons per year more recently, and the U.S. is the single largest national market for California almonds.

United States accounts for over 98 percent of the almonds imported into Japan; in Europe, it shares the market with Spain and the other producing countries.

EU member countries, primarily Spain and Italy, historically have been the main almond producers in the world. However, even though Spanish almond production has risen, the EU has become an important net importer due to the decline in the Italian almond industry and the rise in EU almond consumption. This development has occurred simultaneously with the increase in California's almond production and has made California the largest almond supplier to the EU.

From 1986 to 1991, more than 50 percent of California almond exports went to the EU, and Germany alone accounted for close to 30 percent of total California almond exports. Between 1970 and 1990, the U.S. share of sales to the main almond importing countries of Germany, France, Italy, the Netherlands, and the UK rose from 37 percent to 70 percent, representing an increase in sales from 16,500 to 77,200 tons kernel weight.

Spanish almonds compete with California almonds primarily in the EU market. The EU, however, has not used any significant trade barriers to restrict almond imports and protect Spain. The longstanding nominal import tariff of 7 percent has not been an important impediment to trade. Under the 1989 U.S.-EU agreement, the tariff was replaced with a tariff-quota arrangement. A nominal tariff of 2 percent applies to a quota of 45 million kilograms (about 50,000 tons), with additional quantities subject to the 7 percent tariff (Worldtariff 1992). The tariff faced by Spanish almonds in the EU prior to Spain's accession to the EU was so low that its suppression has not significantly improved the country's competitive position (Moulton 1983). Nor are trade restrictions important for filberts, a potentially important competing nut. Turkey, the largest producer of filberts, has a 25 million kilogram quota (about 28,000 tons) of filberts which enter the EU duty free, with a 4 percent tariff levied on additional volumes.

Past research on the European demand for almonds has treated California and other almonds as distinct products. Bushnell and King (1986) analyzed export demands for California almonds, using the Spanish almond prices or per-capita consumption of European almonds to account for the effects of European production on U.S. exports. Bushnell and King reported difficulties in using Spanish almond prices, as their multicollinearity with U.S. prices led to "wrong signs" for demand equations for the United States, West Germany, and Canada. They therefore included per-capita imports of European almonds in their equations for export demand for U.S. almonds. Alternatively, one may take the correlations between U.S. and Spanish (and Italian) prices as evidence against source-country differentiation of almond markets, and analyze instead demands for all almonds, irrespective of source, within each country. We report, in this chapter, the first estimates for total almond demand within each of the major European almond consumers; in Appendix A we present technical evidence in support of this analysis of an integrated market for almonds. Our estimates incorporate several additional modifications to the Bushnell and King work that strengthen the linkage between the econometric work and the underlying theory of demand for almonds or other commodities. These extensions and modifications permit the construction of a complete model of the almond industry, capable of describing, and forecasting, the evolution through time of almond prices, quantities, and acreage.

An important distinction between the European markets and markets elsewhere is the use of substitute nuts, which is particularly important in the large Northern European markets. Alston and Sexton (1991) have identified filbert prices as an important influence on California almond exports. The European confectionery industry can replace almonds with filberts in many of its processes, particularly as filbert prices fall and almond prices increase. In contrast, in the United States, Japan and Great Britain, it appears that almonds have no good substitutes. We suspect that this result is related to their greater use in these markets as a snack food, and perhaps as a recognizable stand-alone ingredient, such as the slivered almonds in cereals and on cakes, rather than as a ground-up, processed ingredient for marzipan and other confections.

The apparent differences in tastes and uses for almonds in different countries led us to estimate separate functions for the various almond-importing countries, rather than treating the EU (for example) as a single entity. Although treating the EU as a unit would simplify the analysis, it would also lead to a loss of information about differences in almond consumption behavior among the countries. Given the ultimate purpose of this study, it seemed more appropriate to fit specific models for each country (or at least for the most important ones) and then to aggregate these when there is interest in the total market response.

In addition to the European countries, demand functions for the United States, Canada, and Japan were also estimated. The California industry completely dominates the markets in the United States and Japan. Over 99 percent of Japanese imports are supplied by California, while U.S. almond imports are insignificant. California supplies over 75 percent of Canadian almond imports.

Knowledge of demand relationships in a subset of the world's markets gives only a partial accounting of the total demand for almonds. In the almond industry, inventories of nuts are generally carried over from one year for sale in the following year; an inventory demand function is estimated to describe the evolution of these stocks. Finally, the model is closed with a Rest-of-World (ROW) demand equation that shows the relationship between prices, exogenous variables, and the quantities of almond sales to other markets that are necessary to clear supplies in each year. Since the bulk of sales outside the "large" countries (United States, Canada, Japan, Germany, France, Great Britain, the Netherlands, and Italy) are to a set of medium-sized countries, we estimate separate demand functions for seven of these countries to provide a means of checking the constructed market-clearing ROW demand function.

In Section 5.5, demand estimates for the large countries are presented, along with the estimated storage equation. Spanish net exports are treated as exogenous. We construct a ROW series (calculated as U.S. net exports, plus Spanish net exports, plus Italian exports, less Italian imports, less net imports by Germany, France, the Netherlands, Great Britain, Japan, and Canada), and estimate an ROW demand function, also presented in Section 5.5. Then in Section 5.6 we analyze separately the demands of the next seven largest consuming countries which, except for Australia, are all in Europe.[3]

5.2 Theoretical Considerations in Analyzing Almond Demand

Consumer Demand

The economic theory of consumer behavior predicts that a number of factors influence the amount of a product such as almonds that consumers buy. The most important of these factors is generally the price charged for the product. The price-quantity relationship is crucial because price and/or quantity placed on the market are decision variables for individual firms or an industry-wide organization such as the Almond Board. The relationship between price charged and quantity sold is usually quantified using the price elasticity of demand (the percentage change in quantity purchased due to a one-percent change in price). The price elasticity esti-

[3]Switzerland is actually a larger almond market than Canada; however, because Canada is a larger market for California almonds, and because the close integration between the Canadian and the U.S. markets dictates a common treatment in any price discrimination policy, Canada is treated as one of the large markets.

mate is a critical input into devising an optimal reserve strategy because it indicates the impact on industry revenue from implementing various reserve strategies.

It is also desirable to specify and estimate models that incorporate as many as possible of the other factors influencing almond demand, so that their effects can be held constant, statistically, in order to obtain an accurate estimate of the price responsiveness. From economic theory and previous statistical analyses of demand, factors that are likely to be important determinants of consumers' demand for almonds include:

1. Consumers' purchasing power, measured in this study by personal consumption expenditures on all goods and services.

2. Market prices or quantities of substitute commodities. Prior analyses of the almond industry (Bushnell and King 1986; Alston and Sexton 1991) have indicated a strong filbert-almond link.

3. Exchange rates. Since nearly 2/3 of the California almond crop is exported, the exchange rate between U.S. dollars and the currency in key importing countries such as the Germany and Japan is a major factor influencing the cost of California almonds in those countries and, hence, consumption of them. Exchange rates are accounted for in the subsequent analysis by converting all monetary measures into units of the demanding country's currency, and then deflating. This procedure accommodates the concerns in Bjarnason, McGarry, and Schmitz (1969) that the price series used in international supply and demand analyses reflect the real prices faced in each country.

4. Population. The effect of population growth is captured by estimating models of per capita demand.

Derived Demand

Figure 5.1 represents product flow in the California almond industry schematically, with particular attention to the determination of prices and quantities at various different stages. There are at least three price-determining stages in the industry, which could be the focus for econometric work. With data on the prices charged by handlers, one could focus on the price and quantity of final production, aggregating the flows to domestic and foreign purchasers. With data on the prices received by growers and other suppliers to the almond marketing sector, one could focus on the prices and quantities of farm product and processing inputs. Finally, one might investigate the derived demand for the inputs used by almond growers. A full, disaggregated model of the industry would encompass all of these sectors; earlier work, in particular Bushnell (1978) has included elements from the entire chain of markets depicted in Figure 5.1. Additionally, one might focus on particular elements, such as the factors determining the markup between the prices received by growers and the prices received by handlers, a feature in particular of Bushnell and King (1986).

Given the close relationship between grower and handler prices, as demonstrated by the margin relationship in Bushnell and King, one may simplify the analysis and analyze the derived demand for almonds faced by growers. This procedure aggregates over all the uses to which almonds are put, and permits the identification, in particular, of a single elasticity of demand for domestic almond sales. Since the marketing orders governing sales of California almonds have had effect at this level—rather than controlling, for example, the quantities directed to different end uses, such as food-service, snack, or manufacturing—this is an appropriate place to focus the analysis, especially since there appears to be a near-constant markup. However,

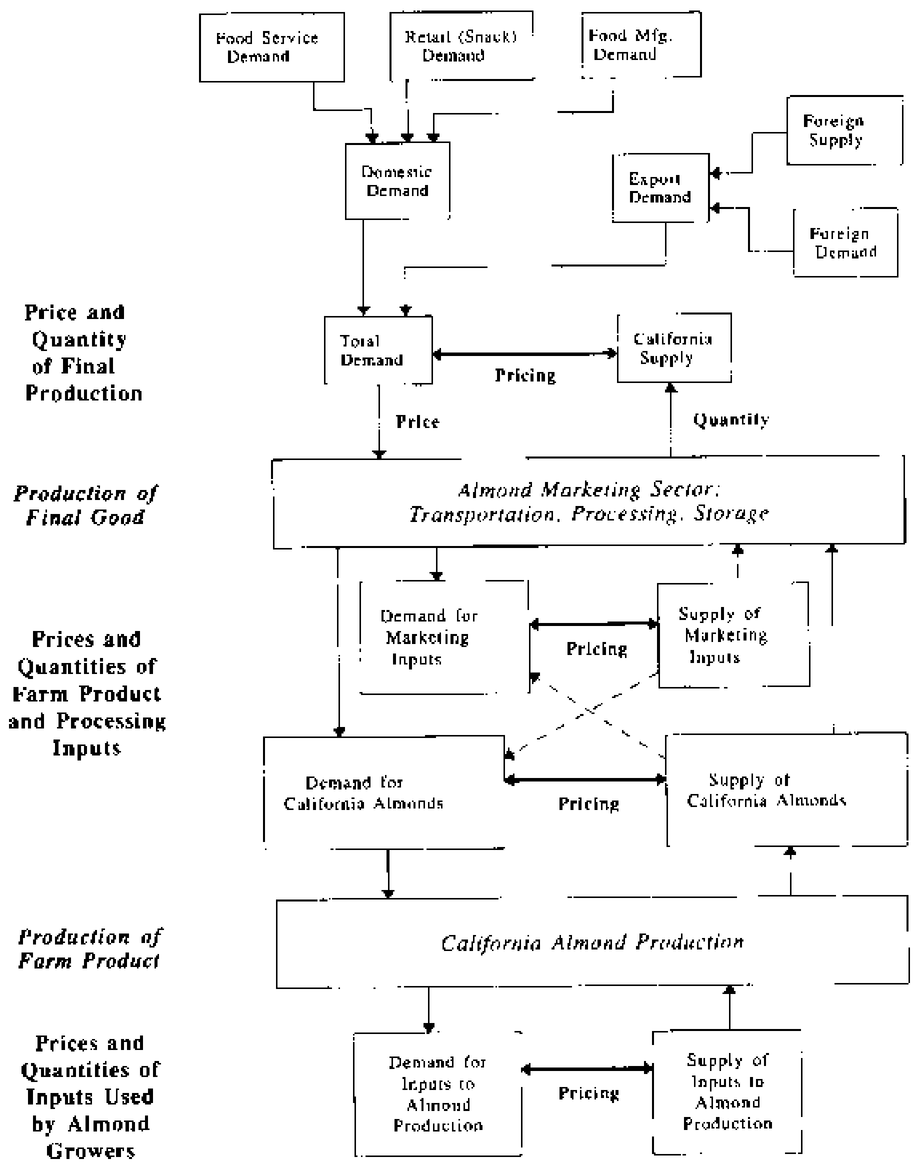
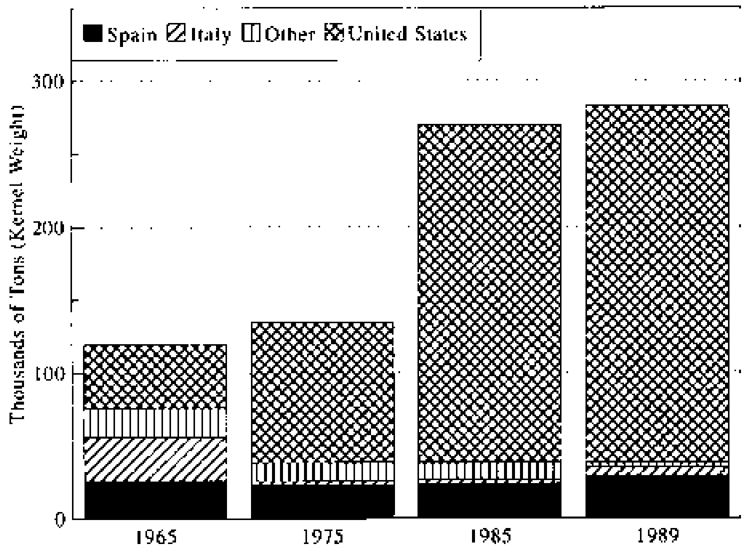


Figure 5.1: Schematic Diagram of California Almond Industry



Non-US supplies: volume of exports (Source: FAO)
US: Total harvests (Sources: USDA, ABC)

Figure 5.2: World Almond Supplies by Producing Countries

since the latter feature is an important condition for the analysis of derived demand, the constant-markup assumption is validated in Appendix A.

The demand facing growers or the market intermediaries, illustrated below in Figure 5.3, is a *derived* demand. If marketing-sector services are provided under competitive conditions, derived demand for any quantity of almonds can be found from the final or primary demand merely by subtracting the cost per unit of providing the marketing services required to transform raw almonds at the farm into the form required by end users.

Economic theory suggests that derived demand is influenced by the same factors that influence primary demand as well as an additional set of factors that influence the costs incurred by market intermediaries in supplying the raw product to the various end users. These costs, associated with transporting, storing, processing, wholesaling, and retailing almonds and almond products, comprise the *margin* between primary and derived demand.

The derived demand for inputs into a food processing industry depends on the prices of other inputs (such as labor and capital), and the technology of processing, as well as the price of the raw materials. Thus, the demand for semi-processed almonds would be expected to depend on the prices of substitutes in food processing as well as substitutes in final consumption.

Residual Demand

California lacks a monopoly on world almond production. Although California now annually supplies over three-fourths of the world's almond trade[4] (see Figure 5.2), it

[4] We consider here the shares of the world's marketed almonds. For the United States, both domestic consumption and exports are included. The other major producers consume much less, and lack good data for domestic consumption. World marketed supplies are therefore defined as

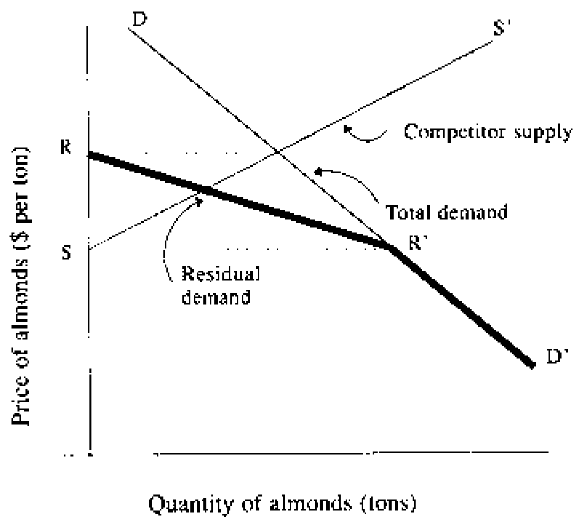


Figure 5.3: Residual Demand for California Almonds

faces important competition for export sales from foreign producers, most notably Spain. The presence of foreign competitors means that California almond producers usually do not face the total demand for almonds in a given country's market. Rather, California faces the demand that remains after taking account of foreign supplies. This *residual demand* is illustrated in Figure 5.3 for a representative country. Total demand for almonds at various prices is represented in the figure by the line *DD'*. Supply of almonds by foreign producers at various prices is indicated by the schedule *SS'*. By subtracting the volume of outside supply from total demand at each price, we derive the schedule *RR'D'* of residual demand facing California growers. For prices below *S* per ton there is no competitor supply, so the residual demand is equal to total demand.

This chapter presents statistical evidence that U.S. and Spanish almonds are very close substitutes in most consuming countries. Our approach in this study is, thus, to estimate total almond demand in the key consuming countries. Residual demand for U.S. almonds is then derived by netting Spanish supply from the total demand functions.

Time Framework of Demand Analysis

A difficult issue in analyzing demand is determining the time period or length of run to which the analysis should apply. Due both to stock-adjustment and habit effects, and to dynamics in the food-processing industry response, we expect a gradually increasing response in sales to a permanent price change.

Opportunities to incorporate length-of-run considerations in demand analysis depend upon the type of data that are available. In the case of almonds, data are available primarily on an annual basis, reflecting the fact that almonds are a crop

total U.S. supplies, plus net exports by other nut producers.

with an annual harvest cycle and, for the most part, an annual price determined by the magnitude of that harvest. Estimates of demand response to price changes obtained from these annual data should, therefore, reflect buyers' short- to medium-run responses. Data reflecting purchasing decisions over a year's time should not be biased by consumer inventory effects, and purchasing patterns (habits) have ample opportunity to adjust.

The short- to medium-run demand effects that are observed when analyzing annual data on the almond industry are the important effects for purposes of *allocated* reserve policy recommendations, because these reserve decisions generally have force for at least a year's time; *unallocated* reserves are normally released or otherwise disposed of prior to the next year's harvest.[5]

Equilibrium and Rest-of-World Demand

We assume that net imports (exports) of almonds in each of j countries, (Q_j, $j = 1, \ldots, J$) are determined by the real price of almonds in the country (p_j), real total consumption expenditures in the country (Y_j), and other exogenous variables (Z_j). Further, the sum of net imports and exports is zero (supply equals demand). If all prices are linked, so that they can be represented in terms of one country's price and the exchange rate (X_j) that expresses country j currency in terms of the base country, then in each period the following equations must hold:

$$Q_{jt} = f_j\left(p_{jt}, Y_{jt}, Z_{jt}\right), \; j = 1, \ldots, J, \tag{5.1}$$

$$\sum_{j=1}^{J} Q_{jt} = 0, \tag{5.2}$$

and

$$p_{jt} = g_j\left(p_{1t}, X_{jt}\right), \; j = 2, \ldots, J. \tag{5.3}$$

There are $2J$ equations in this system, sufficient to determine J prices and J quantities. One might then estimate the J demand functions in (5.1) and the $J-1$ price rules in (5.3); to simulate the model for different values of the exogenous variables, substitute these variables into the estimated equations, impose the equilibrium condition, and solve. In practice, we explicitly estimate demand equations for eight countries, as well as seven price rules, then construct an aggregated ROW series that clears markets, and estimate a demand equation for ROW. The prices in the demand equations are the average import price (total value of imports divided by total physical volume of imports, C.I.F. port) for all countries except the United States, for which the average per-unit grower receipts (or farmgate price) is used, while the average German import price is used for ROW demand.

The Estimated Structure

The theory outlined in the preceding section was used to create a structural model of the almond market, which was estimated and used in subsequent policy analysis. In this model, there is a single market for the almonds grown in the United States, Spain, and Italy, and sold in the industrialized economies of the OECD. International trade in almonds is relatively free, so that stable relationships exist among the prices of almonds in different countries. In the almond industry, in common

[5]Under the almond marketing order, the Almond Board of California (ABC) estimates the proportions of growers' deliveries to handlers that are inedible, which are identified as "Loss and exempt." The remainder of the deliveries are subject to the allocated and unallocated reserve requirement. Allocated reserves have a specified final destination or use, such as exports, almond-butter programs, oil, or livestock feed. Unallocated reserves are held off the market, and may later be sold in the primary marketing channels.

with many other agricultural industries, current supply does not depend on current prices: the quantity of almonds in the market in a particular year is determined by earlier planting decisions and weather-influenced yields, plus stocks of almonds carried over from the previous year.

The principal almond-consuming countries of Western Europe, plus Japan and Canada, are treated as indicated in the preceding section. Net import demand for almonds is determined by prices of almonds and, in countries where almonds are used extensively in marzipan and other confectioneries, filberts, as well as by real consumption expenditures, as in equation (5.1).

In almond-producing countries, the analysis must be different. We calculate domestic purchases in the United States as the difference between contemporaneous supplies (current harvests plus uncommitted inventories carried in less uncommitted inventories carried out) and net exports. This demand is, of course, derived from many demands for final consumer products, as most almonds, in the United States and abroad, are processed further and combined with other ingredients in a variety of products. With carry-in predetermined, it remains to identify and estimate a storage equation to determine inventories carried out. The combination of this storage equation with the U.S. demand equation and predetermined harvests and carried-in inventories is equivalent to a net import (export) equation for the United States, as specified in equation (5.1).

It would have been desirable to use a similar procedure for the other two major almond producers, Spain and Italy. However, the harvest data for those countries is unreliable, with measured harvests growing rapidly (particularly in the early years) while exports remained approximately constant. The resulting measured series of domestic consumption quantities, for both Spain and Italy, are largely independent of prices. This is likely a result of the different sources of the two sets of series, harvests and trade. Trade statistics are constructed at a country's borders, where incoming or outgoing shipments are tabulated. Harvest data are the results of more-or-less systematic sampling procedures, often depending upon the goodwill of growers who have little incentive to participate actively. Furthermore, in both Spain and Italy large parts of the almond crop have historically come from unirrigated trees on marginal land, collected on an informal basis. Such production is rarely measured accurately. For whatever reason, it has proven impossible to estimate domestic demand equations for these two countries. Instead, import and export equations were constructed and estimated for Italy, while Spanish net exports were treated as if they are independent of prices, as discussed below.

The two countries are treated differently because of their histories, which in turn influence our ability to successfully estimate behavioral relationships. Italy was, during the 1950's, the world's dominant almond producer. Due to Italy's declining role in the world almond market, data series describing the Italian almond market increasingly resemble those series for the non-producing almond consumers. However, this change has taken place slowly, with imports exceeding exports only once prior to 1985; since 1987, Italy has been a net importer of almonds. It has therefore been impractical to analyze a net import (or export) function for Italy; instead, two functions have been estimated, with the real income indicator a determinant of gross imports but not of gross exports, and with both imports and exports determined by price and by measured harvests.

We have been unable to develop useful estimates either of Spanish demand or of Spanish net exports. Therefore, when the equations are combined, later, into a simulation and policy-analysis model, it is necessary to provide values for Spanish supplies. Fortunately, we have been able to estimate an acreage response, which can be applied to estimate the long-term response of Spanish supplies to changes in prices. The lack of a domestic demand equation for Spain (which is implied by the lack of the derived import and, especially, export equations) is actually not very serious. The Spanish domestic market is small relative to the total harvest, so the simultaneous supply response to, for example, increased prices, where domestic demand is squeezed out and product is diverted to international markets, is unimportant, compared with the large fluctuations due to the variations in harvests. Nonetheless, this is an important area for future work, which may depend upon improved techniques for treating systematically mismeasured data.

The simulation model involves eleven demand equations: the U.S. domestic consumption equation and carryout storage equation, in combination with predetermined supply, corresponding to equation (5.1) for $j = 1$, six net import equations corresponding to equation (5.1) for $j = 2, \ldots, 7$, the Italian import and export equations corresponding to equation (5.1) for $j = 8$, and the aggregated ROW equation corresponding to equation (5.1) for the remaining countries in the world in combination with the equilibrium condition, equation (5.2). In addition, we will need seven price rules, of the form of equation (5.3)—note that the German price is used in the ROW equation. In a later section, we present statistical analyses suggesting that such price rules do exist—there is a "Law of One Price" in the almond market; in the simulation and policy-analysis applications we use a markup-rule derived from historical experience.

We have, then, the elements of a complete model of price and quantity determination in the world almond market. The estimated equations reflect closely the structural form described by microeconomic theory; these equations can then be used to simulate the evolution of the almond industry, and for the analysis of alternative reserve, marketing, and production policies in the industry.

5.3 Statistical Considerations in Estimating Almond Demand

Single Equations vs. Demand Systems

The static theory of consumer behavior implies a set of mathematical conditions or restrictions that must hold among demands for products as a group. Estimates of demand can sometimes be improved by imposing these conditions on blocks of demand equations and estimating the equations jointly as a *system* rather than individually.

Problems are often encountered in estimating demand within a systems framework. To begin, when interest focuses on a single commodity such as almonds, errors made in estimating other demands in the system can pollute estimates for the commodity of interest. Secondly, including a commodity with a relatively minor share of total food expenditures in a complete food demand system can be impractical. One alternative is to invoke separability assumptions concerning consumers' budgets and to estimate a demand system for a subset of goods—for example, for different types of nuts.[6] Serious problems limit the utility of this approach for almond demand. The separability assumption, in particular, may be inappropriate because almonds are used most extensively as a food ingredient, where they may substitute with a number of different food products. In addition, in a partial system approach, total expenditure on all goods is replaced as the income variable by expenditure on goods included in the system. The resulting estimates of price and income elasticities reflect only partial responses and are inappropriate measures of the demand response to changes in income or total expenditure or the demand response to price holding constant *total* income. The partial system approach to demand analysis is especially useful for analyzing the strength of substitution re-

[6]The separability assumption is that consumers allocate their budget to broad food classes such as meat, breads, vegetables, nuts, etc. and that the allocation of expenditures within such a class, a separable group, depends only on the prices of goods within the group and on total expenditures on the group.

lationships among related goods and testing specific hypotheses, but is not clearly useful as a basis for an industry simulation model.[7]

Demand for Consumption vs. Demand for Storage

The almond market is subject to large year-to-year price fluctuations. An important consideration in analyzing demand for almonds and in implementing reserve policy is that industrial users of almonds may elect to acquire and store almonds across crop years. For example, food manufacturers may purchase almonds in excess of their current requirements in high-production, low-price years in anticipation, based on the alternate-bearing cycle, of a subsequent low-production, high-price year.

If measured disappearances of almonds include both consumption and storage uses, then observed responses of demand to price will include both consumption demand and storage demand responses, and the resulting estimate of the price elasticity of demand will be biased as an estimate of the elasticity of final consumption demand response. For example, in high-production, low-price years, if stockholding behavior causes almond users to buy almonds both for current use (consumption) and for future use (stockholding) in anticipation of higher future prices, the measured response of demand to the low price based on disappearances data would be greater than the true consumption response.

There is little information available on stockholding of almonds outside the industry, although industry experts consider that it is not an important phenomenon in most countries. We investigated various statistical approaches to measuring any stockholding effect on measured demand.[8] These approaches yielded no conclusive evidence of a stockholding effect, so the final demand estimates presented here effectively assume that disappearances of almonds reflect only consumption responses and not storage outside the industry.

General Form of Almond Demand Equations

Based on the theoretical arguments above, it is assumed that the per capita demand for almonds in country K, defined as net imports of almonds, is a function of

1. the price of almonds imported by that country (P^K),
2. the price(s) of other competing nuts (PCN^K),
3. per capita consumption expenditures (Y^K), and
4. the prices of other producer or consumer goods that affect the derived demand for almonds, as represented by the consumer price index in that country (CPI^K).

Per-capita demand can then be written

$$Q_t^K = f\left(P_t^K, PCN_t^K, Y_t^K, CPI_t^K\right). \tag{5.4}$$

All of the monetary variables in this equation are expressed in nominal domestic currency units in country K. Consumers (and processors) in country K are concerned with these prices and income in terms of their domestic currency. Since

[7] Despite these misgivings about the utility of a systems approach to analysis of almond demand, we did experiment with specification of a partial demand system for the United States, consisting of demand for five nuts: almonds, filberts, peanuts, pecans, and walnuts. The results for almond demand were broadly consistent with the single-equation results reported in Section 5.5; moreover, the system results indicated that the alternative nuts were not good substitutes in the United States for almonds.

[8] For example, if nonindustry speculative stockholding were important, a variable such as yields, which given the alternative-bearing phenomenon is a significant predictor of storage within the industry, might be an important variable in explaining disappearances of almonds.

consumer (and producer) theory shows that it is only relative (or real) prices that matter, we deflate the monetary variables by the CPI.

Country K's per-capita import demand function for almonds, formulated as a linear model, can therefore be written in terms of real prices and real income per capita as

$$Q_t^K = a_0 + a_1 p_t^K + a_2 pcn_t^K + a_3 y_t^K + \epsilon_t \tag{5.5}$$

where the lower-case letters denote real (deflated) values of the nominal variables defined above (e.g. $y_t^K = Y_t^K / CPI_t^K$), and ϵ_t is a random disturbance. We expect to find $a_1 < 0$ (i.e., a negative own-price effect), $a_2 > 0$, and $a_3 > 0$ (positive substitution and income effects).

The econometric specification (5.5) includes as explanatory variables the prices of both almonds and competing nuts (specifically filberts), variables which would seem to be determined simultaneously with quantities purchased. If this simultaneity is statistically important, then the OLS estimators will be inefficient and inconsistent, and alternative estimators are preferable. It will therefore be necessary to investigate alternative estimators, and to seek evidence for simultaneity. This investigation is describe in Section 5.6.

A number of functional forms were tried, including linear equations, double-log models, where all of the variables in (5.5) are replaced with natural logarithms of their actual values, and linear models with a quadratic own-price term. These are relatively simple functional forms and are, perhaps for this reason, among the most commonly used demand models.

5.4 Data for the Analysis

In this chapter's econometric modeling, we use data from four sources: the Almond Board of California (ABC) and its predecessors, the U.S. Department of Agriculture (USDA), the United Nations Food and Agriculture Organization (FAO), and the European Union's statistical office, Eurostat. The data used in this chapter are listed in Tables C5.1–C5.7 of Appendix C.

U.S. Almond Statistics

Two data sets describe the U.S. almond markets: first, figures taken or derived from the monthly and annual reports by almond handlers to the ABC, which reports in turn to USDA; and second, the USDA annual series on average prices received by growers. The ABC handler reports include the volume of nuts received by handlers from growers, and their disposition. as stocks, reserves, or shipments to buyers outside the industry. We define total crop-year *availability* as stocks carried in plus new-crop receipts less reserves and allowances for losses in storage.

In our econometric work, we identify as U.S. demand the volume sold by California almond handlers in U.S. markets during a given crop year t, which runs from July 1 of year t to June 30 of year $t+1$. This is calculated as total availability, less U.S. calendar-year net exports NX_t^{USA}, less stocks carried out S_{t+1}. Availability is the harvest received by handlers H_t (the ABC *Receipts* series) plus stocks carried in S_t. Stocks are identified as handler uncommitted inventories as of June 30 of each year. We have thus identified the sales in the U.S. market as

$$QS_t^{USA} = S_t + H_t - NX_t^{USA} - S_{t+1}. \tag{5.6}$$

The domestic consumption series thus calculated shows wider year-to-year variations than does the ABC reported domestic crop-year domestic-disappearance data. There are two sources of the variation between the two series. First, the series used here includes handler commitments as sales within the year in which the sale is committed, while the published series attribute the sales to the year when delivered.

Second, as discussed in the next subsection, exports are measured on a calendar-year basis, while stocks and production are on a crop-year basis. It is argued below that the calendar-year basis of the export data does not seriously interfere with the accuracy of the resulting estimates, while the inclusion of commitments in the sales data is consistent with theory. The future availability of long crop-year time series on California exports will certainly improve the accuracy of the statistical work.

To analyze demand relationships, we need information about the prices paid by almond purchasers, or received by handlers. Since our data for U.S. consumption are primarily on a crop-year basis, we would like a measure of the average price received during the crop year by California handlers. Such a price series is not available. Instead, we can choose between (*i*) the unit value of U.S. exports—a measure of the average price of U.S. exports—which is measured on a calendar-year basis, or (*ii*) the average farmgate price, which is total payments from handlers to growers, divided by the quantity of almonds handled, calculated on a crop-year basis. While the export price is preferable on theoretical grounds—in a competitive market profit-maximizing handlers will receive the same prices from domestic and from foreign purchasers—the calendar-year data are not appropriate for crop-year demand analysis.[9] The most useful price series for the U.S. market is the farmgate price, deflated by the consumer price index to form p_t^{FARM}, measured in 1983 dollars per pound, on a kernel-weight basis.[10]

Trade Statistics

Eurostat and FAO are alternative sources for data on international trade in almonds. The FAO data cover 1961–1989, and include exports and imports by all countries. In addition, we use series from the FAO on harvests for Italy in the estimation of functions describing the Italian market. The Eurostat data, from the European Union Foreign Trade Statistics (NIMEXE) cover trade by European Union member countries, listing exports and imports, volume and value, with data for each member country broken down by its trading partners, for the period 1970–90.

Both databases include data on a calendar-year basis on both the volume of almond trade, measured in metric tons, and the value, measured in U.S. dollars in the FAO database, and either dollars or European Currency Units in NIMEXE. Dividing value by volume yields the unit value of exports or imports, which is a measure of the average price received for exports or paid for imports. The basis of both value series is the value reported at the reporting-country's frontier; unit import values therefore include shipping costs to the country, unit export values exclude the costs of shipping product abroad.[11]

In our estimations for the European countries, we had to choose between data from FAO and NIMEXE. The latter data run only back to 1970. However, the loss of observations in using the NIMEXE data was in general rewarded by stronger results. This may be due to more consistent classification of nut data in the NIMEXE data base. For example, the data for at least Great Britain in the FAO data set appear to be incorrect, perhaps due to changes in units of measurement or perhaps grouping

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[9]We constructed an approximate crop-year export-price series, using the industry's month-by-month export series, and found that this series conforms much more closely to the farmgate price series than to the calendar-year unit export values. There remain important differences between the constructed series and the farmgate series—it appears in particular that farmgate prices are bid up relative to export prices (and, presumably, other handler prices) when harvests are smaller than expected.

[10]Because most almonds are marketed in shelled form, prices and quantities in this chapter are on a kernel-weight basis. For California almonds, kernel weight is about 60 percent of the inshell weight, while for almonds grown in Europe kernel weight is about 30 percent of inshell weight.

[11]For importers the prices are C.I.F.: cost at the receiving port including insurance and freight but prior to landing. For exporters the prices are F.O.B. at the exporting port: the prices exclude insurance and freight.

of several nut varieties into the almond commodity classification. For Italy and for the Netherlands, both of which have well-established almond-trading systems (Italy is a traditional exporter, while Rotterdam is the site of important almond brokerage activities), the FAO data and the NIMEXE data are both consistent, and plausible prior to 1970, and so the longer FAO series is used. Since some of the countries are only estimated after 1970, the shorter period is used for the ROW series, discussed below.

To calculate U.S. consumption, we subtract U.S. calendar-year net exports from crop-year industry sales. If all U.S. exports were shipped between July 1 and December 31, our consumption estimate would be correct. However, since exports are shipped throughout the calendar year, we are faced with a timing problem: exports from the last half of the previous crop year and the first part of the current crop year are used in the calculation of current crop-year consumption. The timing problem is made somewhat worse by the industry's shipping practices: due to lower tariffs on the first 50,000 metric tons of almond shipments to the European Union each year, there is incentive to schedule shipments to arrive in European ports at the beginning of the calendar year. As a result, more than a quarter of each crop-year's exports are typically shipped during the first quarter of the following calendar year.

Two phenomena mitigate this timing problem. First, there is heavy shipping volume between July and December: more than half of the crop-year exports are typically shipped during those six months, presumably in order to meet holiday-season demand for almonds in the European markets. Second, during most of the first six months of the calendar year, the period during which the timing problem manifests itself, there is sufficient information to accurately predict the next harvest, and prices should already reflect those supplies.

Once the period of fruit-set has passed, in February and early March, the year's harvest can be predicted accurately. We expect, then, that prices remain relatively stable through the remainder of the calendar year, and are governed by the known, or accurately predicted, harvest for the crop year which falls within that calendar year. A good crop in, for example, 1984 will be forecast tentatively in 1983, from knowledge of the current state of the alternate-bearing cycle and the age-structure of the tree stock, and relatively precisely in early March of 1984. With no further important information through the remainder of the year, calendar-year exports should be expected to be relatively high, as stocks are sold off in anticipation of the good crop.

To summarize, the timing of exports, in combination with the early availability of good information on projected harvest, allows us to associate about 5/6 of each calendar-year exports with the coincident crop year. The high volume of exports at the beginning of the year remains a problem, but has not, we argue, seriously interfered with the accuracy of our estimates.

The series for ROW demand was constructed. The marketed world supply was assumed to be equal to U.S. supply (i.e., U.S. harvests plus uncommitted inventories), plus Spanish net exports, plus Italian exports.[12] ROW demand is then the difference between this supply and measured demand, which is U.S. demand, plus Italian imports, plus net imports by Germany, France, the Netherlands, Great Britain, Japan, and Canada, plus the end-of-year uncommitted inventories held by California almond handlers. All these data are from the FAO database, except U.S. harvests and inventories, which are from the ABC handler reports.

[12]This measure differs from the total marketed supply discussed at the beginning of the chapter by the exports from small suppliers (Turkey, Morocco, Tunisia, Portugal, China and Chile), which accounted for about 2.2 percent of that measure. That measure understates true total world demand by the consumption of untraded almonds outside the United States.

Macroeconomic Statistics

The estimated demand equations include a number of indicators and factors related to the broader economic environment. To convert unit trade values measured in nominal U.S. dollars to the various national currencies in real (inflation-adjusted) terms, we use calendar-year annual-average market exchange rates and the consumer price index (CPI) for each country, as published by the International Monetary Fund (IMF). To measure consumers' purchasing power, we use the series on private domestic consumption expenditures, also as published by the IMF. Consumption expenditures are also deflated to constant national-currency terms using the CPI, and both consumption expenditures and the almond quantities used in the demand equations are transformed into per-capita terms using the IMF's population series.

5.5 Estimation Results

In this section we describe the preferred statistical models of final-consumption demand for almonds in the United States, five major European countries, Canada, Japan, and Rest-of-World, as well as an estimated equation describing uncommitted inventories.

Functional Form

For each of the large-country equations, we formulated a Box-Cox test, which in all cases rejected the hypothesis of a linear relationship between prices, consumption expenditures, and almond purchases.[13] We conclude that, except for ROW, demand is non-linear. We could not use a similar criterion to investigate a semilogarithmic specification, as the numeric procedures to estimate independent Box-Cox parameters for the dependent and independent variables did not converge. To choose between semi-log and double-log specifications, we relied upon the adjusted R-squared coefficient to indicate goodness-of-fit. In all cases except ROW, the double-log specification fit best, and we report the results for those models. For ROW, the linear model was best.

Treatment of Abnormal Data

We examined the residuals from initial estimation of the demand models in an attempt to identify outlier observations. Hypothesis tests require that the stochastic term in the regression equation be normally distributed about a zero mean. If this condition holds, we can state that the probability of observing a residual which is more than twice the estimated standard deviation of the regression equation is less than 0.05. When we encounter such data points, we must decide whether to "believe" that these points represent normal random fluctuations in the data, or whether they represent abnormal situations or errors in the data, when the underlying model which we are attempting to estimate cannot be expected to hold. If we include abnormal situations, then our parameter estimates may be unduly influenced by circumstances which will rarely, if ever, be repeated. As our goal is to build a model which is useful for the "normal" circumstances, we have chosen to systematically exclude data that are identified as "abnormal."

We treated as "outliers" in each country's models those years for which the residuals in simple OLS regressions are more than twice the standard error of the estimate. The existence of such outliers does not imply that the OLS model is in-

[13] In the simulation and policy-analysis applications of Chapters 6 and 7, the double-log formulations must be linearized. The resulting loss of accuracy is not measured by the Box-Cox procedure for values away from the means of the linearized functions. However, for the simple exercise of identifying the parameters of demand, the Box-Cox procedure does accurately reject the inferior (linear) functional forms.

Table 5.1: Outliers in Simple OLS Demand Regressions

Equation	*Years*
U.S. Consumption	1973(+), 1979(+), 1986(-)
Germany—Net Imports	1975(-), 1986(+)
France—Net Imports	1972(+), 1975(-), 1983(+)
The Netherlands—Net Imports	1975(-), 1989(+)
Great Britain—Net Imports	1975(-)
Italy—Gross Imports	1972(+)
Italy—Gross Exports	1974(-), 1980(+)

valid: such outliers are to be expected. However, if the model is correctly specified, outliers represent observations with large sampling errors, and the information contained in these outliers is not particularly useful. Hence, we excluded observations from such years in the final regression estimates. The outliers, and the direction of sign of the regression residual, are listed in Table 5.1.

There is a tradeoff between the apparent greater precision of our estimates when these outliers are excluded and a possible loss of information. If, however, the information lost really reflects only one-time events, then their inclusion would reduce the accuracy of our estimates. On balance, we believe that the consistent use of an objective standard—the exclusion of residuals more than twice the standard error of the estimate—contributes to the accuracy and usefulness of our estimates.

Demand Estimates: Large Countries and Rest-of-World

The estimates from our preferred models are listed in Table 5.2. The estimated equations fit the data very well (see Figure 5.4), with adjusted R^2 statistics in excess of 0.90 for the two largest importers, Germany and Japan, as well as for Canada. All of the coefficients have the signs predicted by theory (note that the coefficients listed under "Filbert Price" for "Italy: Imports" and "Italy: Exports" are for Italian Almond Harvests). To test hypotheses, we would like to exclude autocorrelated disturbances; the Durbin-Watson statistics indicate no autocorrelation for the United States, the Netherlands, Japan, and the Italian equations, and are inconclusive for Germany, France, Great Britain, and ROW. Only in the equation for Canada is there evidence for (positive) autocorrelation of the residuals.

It should be noted that while the demand equations for the other countries were for per-capita purchases, those for Canada and ROW were for total purchases. For Canada, the choice was made purely on pragmatic grounds: the total-demand equation gave a much better fit, although with similar elasticity estimates, than did the per-capita equation. Presumably this indicates some weaknesses in the specification of the per-capita demand equation, which is not unexpected given the necessarily arbitrary selection of a functional form, imperfect measures of prices facing purchasers, etc.

In the absence of autocorrelation, the t statistics provide reliable assessments of the statistical strength of the regression estimates. In all equations except the Italian import and export equations, the almond price coefficient is statistically different from zero, at the 95 percent level or higher. Furthermore, for all individual countries except the United States and Canada, the estimated own-price coefficients, which are interpreted as price elasticities of demand, are significantly less than one in

Table 5.2: Almond Demand Regression Results

Country	Almond Price	Income	Filbert Price	Constant	Elasticity of Demand for CA Almonds	R^2 (adj.)	D.W.	Observations
United States	-1.08	0.999		2.12	-1.05	0.68	2.38	1961–89,
	(-6.12)	(3.30)		(2.92)				exc. 73, 79, 86.
Germany	-0.488	1.32	0.252	-2.91	-0.700	0.95	1.31	1970–89,
	(-4.36)	(6.87)	(2.94)	(5.02)				exc. 75.
France	-0.434	0.241	0.0937	0.677	-0.694	0.83	2.35	1970–89,
	(-4.09)	(1.47)	(1.14)	(5.30)				exc. 72, 75, 83.
Netherlands	-0.622	0.336	0.356	-3.15	-1.10	0.82	2.04	1961–88,
	(-7.14)	(2.27)	(2.45)	(-1.92)				exc. 75.
Great Britain	-0.524	0.141		-1.22	-0.640	0.72	1.34	1970–89,
	(-4.93)	(0.03)		(17.23)				exc. 75.
Japan	-0.431	1.85		-12.2	-0.431	0.96	1.73	1962–89.
	(-2.72)	(8.12)		(-4.82)				
Canada	-0.934	1.50	0.651	1.77	-1.28	0.90	0.87	1961–89.
	(-3.81)	(12.65)	(2.01)	(2.49)				
Italy: Imports	-0.164	2.05	-2.15	3.49	-0.716	0.84	1.67	1961–89,
	(0.49)	(3.58)	(-3.19)	(0.26)				exc. 72.
Italy: Exports	0.264		2.07	-31.5		0.85	2.35	1961–89,
	(1.32)		(11.70)	(0.56)				exc. 74, 80.
Rest-of-World	-11215	108.32	3440.8	-16089		0.73	1.50	1970–89,
	(-2.00)	(2.66)	(0.56)	(0.36)				exc. 85
elasticities	-0.8547	1.9618	0.2036					

Notes: The estimated equations are double-log, except for Rest-of-World, which is linear. t statistics are in parentheses below coefficient estimates. Except for Canada and Rest-of-World, the equations are for per-capita demands, and use per-capita private consumption expenditures for Income. The equations for Canada and Rest-of-World are for total, not per-capita, demands, and use total, not per-capita, consumption expenditures for the income variable. The estimated equations are for net imports, in pounds kernel-weight, except for United States, which is Harvests, plus carryin less carryout (uncommitted inventories), less net exports, Italy, for which imports and exports are estimated separately, and Rest-of-World, which is calculated as U.S. Harvests, plus carryin, less carryout, plus Spain net exports, less demands by the other countries listed in the table. Almond Price is the average price of almond imports for each country, in constant national-currency units per pound kernel weight, except the United States, which uses average farmgate price, constant dollars per pound kernel weight, and Rest of World, which uses constant Deutschmark per pound kernel weight. The filbert price for Germany, France, and the Netherlands is the average price of German filbert imports, translated into constant national-currency units per pound. For Canada, average price of Canadian filbert imports is used, in constant Canadian dollars per pound. The Rest-of-World equation uses German price and consumption data. The coefficients under Filbert Price for the Italy import and export equations are for Italian almond harvests, in metric tons (thousands of kilograms). Since all equations except that for Rest-of-World are double-log, the price and income coefficients can be interpreted as elasticity estimates; for Rest-of-World the elasticities are computed at the mean values of the data. The elasticity of demand for California almonds is as defined in equation (5.7). A residual price elasticity is computed neither for Rest-of-World demand nor for Italy exports.

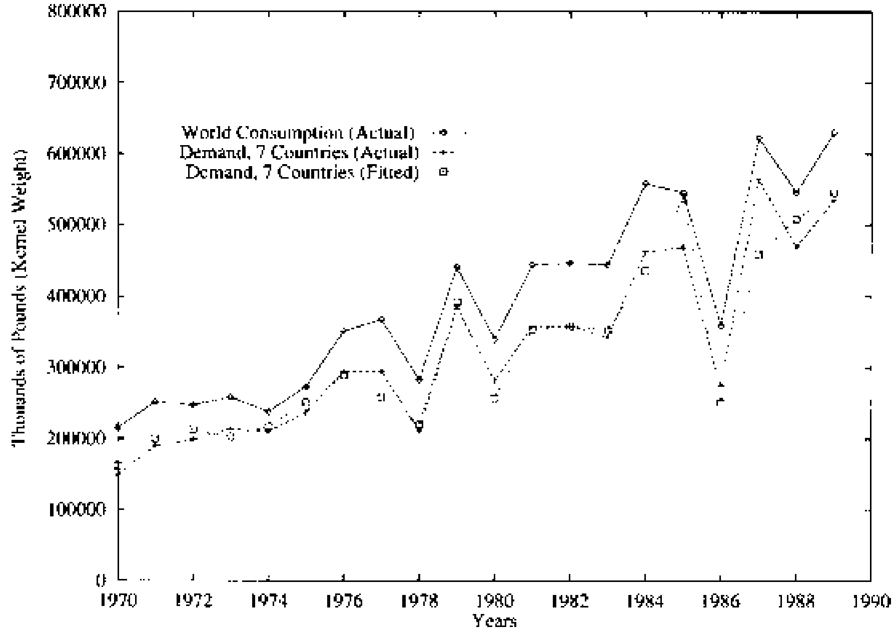

Figure 5.4: Actual and Fitted Values for Demand Regressions

absolute terms: demand is generally inelastic outside North America.

The filbert-price coefficients are all positive, although smaller in magnitude and generally less significant than the own-price coefficients. In most places a one-percent change in filbert prices has less than half the effect of a one percent change in almond prices on almond demand. Finally, the estimated income elasticities are plausible, with estimates close to one for the United States, Germany, and Canada, less than one for France, the Netherlands, and Great Britain, and significantly elastic for Japan, Italy, and ROW.

The demand estimates described above specify that the prices in the individual equations are statistically exogenous. However, the theoretical structure, equations (5.1), (5.2) and (5.3), shows that prices and quantities are determined simultaneously. In addition, among the exogenous variables (Z_{jt}) in (5.1) are several filbert prices, which might be expected to be determined jointly, possibly along with filbert quantities, with almond prices and quantities. Faced with endogenous explanatory variables, single-equation OLS would no longer be either consistent or efficient, and lower-variance estimates could be developed using instrumental-variable methods. If, however, the contribution of each single country's demands to price determination is small, so that almond and filbert prices are statistically exogenous, then methods that treat these prices as endogenous will yield higher-variance, although still consistent, estimates. To evaluate the possibility of statistically important endogeneity, the OLS estimates of Table 5.2 were compared to 2-Stage Least Squares estimates using a series of Hausman tests; these tests, which are discussed in Section 5.6, support the use of single-equation OLS methods.

The policy implications for the California industry depend in part upon the expected responses of foreign producers (especially Spain) to changes in prices. Divide the volume of almonds purchases in country i according to country of origin:

$$Q_i = Q_i^{CA} + Q_i^{RW},$$

where Q_i^{CA} is the volume of California sales in country i and Q_i^{RW} is sales of almonds from other countries. Differentiating with respect to price and multiplying through by price divided by quantity yields an expression for the price elasticity of residual demand for California almonds,

$$\eta_i^{CA} = \frac{p_i}{Q_i^{CA}}\frac{\partial Q_i^{CA}}{\partial p_i} = \frac{Q_i}{Q_i^{CA}}\frac{p_i}{Q_i}\frac{\partial Q_i}{\partial p_i} - \frac{Q_i^{RW}}{Q_i^{CA}}\frac{p_i}{Q_i^{RW}}\frac{\partial Q_i^{RW}}{\partial p_i}$$
$$= \frac{\eta_i}{s_i^{CA}} - \frac{1 - s_i^{CA}}{s_i^{CA}}\varepsilon_i^{RW}, \quad (5.7)$$

where s_i^{CA} is the California market share in country i, η_i is the total price elasticity of demand for almonds in country i, η_i^{CA} is the price elasticity of residual demand for California almonds in country i and ε_i^{RW} is the price elasticity of supply of other (mainly Spanish) almonds to country i.

With little evidence of a strong Spanish response to changing prices, at least in the short run, the appropriate residual price elasticity facing U.S. producers can be calculated under the assumption that $\varepsilon_i^{RW} = 0$. Such elasticities are displayed in the 6th column of Table 5.2. Of course, unequal price changes in different neighboring countries would presumably lead to shifts of (Spanish) product from one country to the next, thereby violating the assumption of no Spanish supply response. Nonetheless, there is a striking similarity in the elasticities facing California exporters in most of the European markets, with elasticities of approximately -0.7 in Germany, France, Great Britain, and Italy. It appears that there is scope for profitable price discrimination against the European markets, as well as against the U.S.-dominated Japanese market.

These residual elasticities are comparable to the elasticities in Bushnell and King (1986), except that the Bushnell and King elasticities were estimated directly, while the elasticities in Table 5.2 are computed from the demand elasticities in each country for all almonds. The elasticities computed here are generally somewhat higher than the Bushnell and King estimates, perhaps because, unlike in the prior work, non-U.S. deliveries to the various countries are not included as explanatory variables. Since these deliveries are correlated with prices, the Bushnell and King parameter estimates have relatively high standard errors. In section 5.5 below, evidence is adduced for a Law of One Price among almonds from different sources; this implies that it is appropriate to estimate total demand in each country, then compute residual demand elasticities.

We found that there was a significant filbert-price effect in Germany and in the Netherlands as well as, to a lesser extent, in France, Canada, and in the ROW equations. In continental Europe, almonds are used extensively as ingredients in marzipan and other confections, in which filberts can be substituted effectively. In Japan and the United States, almonds are more commonly used slivered, or otherwise as a recognizable addition to baked goods and other products, and filberts are not used as substitutes. Including walnut prices in a single-equation demand estimate for the United States confirms experiments with a partial demand system, and indicates that walnuts are not good substitutes for almonds in the United States.

Demand Estimates: Uncommitted Inventories

To close a single-year model of the almond market, so that prices and quantities are determined by the exogenous and predetermined variables, one must account for the inventories held from current supplies into future periods. Following Scheinkman and Schechtman (1983) and Williams and Wright (1991), we analyze year-to-year inventory holdings as an attempt to meet expected future demands, taking into consideration expected future harvests. Williams and Wright (1991) have shown that one can compute a storage equilibrium for any set of current and expected future supply- and demand-determining variables, while Scheinkman and Schechtman (1983) demonstrated that equilibrium storage would be determined by current and past values of yields if harvests were determined by predetermined acreage, an autoregressive yield function, and a stochastic, serially-uncorrelated shock such as weather.

Following this approach, we write a carryout storage equation that includes the information that is available when the final storage decisions are taken. Since by this time the approaching harvest can be accurately forecasted, handlers (and others) can also predict harvests for the year following. The storage equation includes the yield variables that help predict the demands for current harvests in future years. We presume that end-of-year carryout will be influenced by end-of-year expectations of yield in the coming year, as well as the expected difference in the approaching harvest's yield over the yield of the previous year: these are the parts of the yield-predicting equation that account for weather shocks combined with the alternate-bearing cycle in almonds, which is the major cause of fluctuations in year-to-year storage of almonds. In addition, we include a time trend, as inventories have tended to grow with the growth of the industry's annual sales, and a quadratic yield term, to account for the highly non-linear relationship between storage demand and other variables, which is explained well in Williams and Wright (1991).

An alternative to Scheinkman and Schechtman's storage-rule (which is implicitly followed by Williams and Wright) would be to estimate a storage-demand equation, where storage is determined in part by price. As Williams and Wright (1991) argue, there is no basis in economic theory for including storage as an equation in a structural model: there is no utility derived from simply holding stocks. Instead, stocks are held to meet a future demand. To estimate storage structurally, one would forecast future demands, conditional upon future harvests, which can in turn be forecast conditional upon current yields and acreage of various vintages. Imposing equilibrium relationships (especially an intertemporal price condition analogous to a financial arbitrage condition) would then permit the solution of the model for current and expected future prices, with storage sufficient to generate a conditional expected future equilibrium. While this approach is intriguing, and may prove a fruitful avenue for future research, Scheinkman and Schechtman show that it is logically equivalent to the use of a storage rule which includes predictors of future harvests rather than current prices. Indeed, one can interpret the Scheinkman-Schechtman storage rule as a reduced form of a price-determined storage demand, where future-supply-predicting variables have been used as instruments for endogenous price. However, the Scheinkman-Schechtman storage rule adapts more readily to the inherent non-linearity of a price-storage relationship, and thus avoids the weaknesses of that approach highlighted by Williams and Wright (1991).

We presume that handlers who hold uncommitted stocks are rational and well informed. During the spring of a year, they have good information about the likely size of the coming yield. We therefore use the actual values of the future yield as a proxy for their expected values; when the equation is used for future simulation and forecasting, the yield model will be used to generate these data. Our equation for uncommitted inventories is, then, in thousands of pounds (kernel weight),

$$S_{t+1} = \underset{[t=-4.38]}{-120650.0} + \underset{[t-4.07]}{278250.0\, y_{t+1}} - \underset{[t=-2.14]}{120590.0\, y_{t+1}^2} \tag{5.8}$$

$$- \underset{[t=-2.87]}{85752.0\,(y_{t+1} - y_t)} + \underset{[t=2.56]}{4631.4\, T_t}$$

$$R^2_{adj.} = 0.77 \qquad D.W. = 1.92$$

The Integration of the World Almond Market: Evidence from Prices

In the econometric results presented above, we have asserted the existence of a single market for almonds in each country. Our models have suggested that there is one product (almonds) not two (California almonds and European almonds) or more. While this simplification is appealing, it requires statistical validation. We can examine, in particular, the time-series of prices for California almonds and for almonds from other sources, to see if they move together or have a measure of independence. To do this, we can examine the correlations between the various prices, a procedure discussed in Stigler and Sherwin (1985). However, under some circumstances time series of independent variables can exhibit spuriously high correlations. In Appendix A, we check for this possibility by applying the techniques of testing for unit roots and time-series co-integration, developed by Dickey and Fuller (1979) and Engle and Granger (1987), and applied to commodity prices by Ardeni (1989), for example.

Suppose that in fact California and Spanish almonds are not good substitutes. For example, suppose that buyers can use Spanish almonds only for some purposes. Then a disruption of the supply of Spanish almonds should drive up the price of Spanish almonds, without necessarily creating an increasing demand for California almonds. If, on the other hand, almonds from the two countries are very close substitutes, a supply shock to one will affect prices of both. The prices of California and Spanish almonds will move together. If they are *perfect* substitutes, they will move in lockstep, while if they are *identical* commodities, the prices should be identical. These claims rest on the absence of transport costs and instantaneous, complete, competitive arbitrage. Departures from perfect competition in the short run, and measurement errors, as well as transportation costs or imperfect substitutability, can lead to departures from identical pricing or perfectly-correlated prices.

Table 5.3 lists the computed correlation coefficients between average export prices for Spain, Italy, and the United States, and, in the second part of the table, between the changes in the logarithms of those variables (roughly equivalent to percentage or relative changes). There is a very high correlation between the prices earned by Spanish and Italian exporters in international markets. The high computed correlation holds even if one compares rates of change. These coefficients are strong evidence that almonds from Spain and from Italy are close substitutes. The relationship between U.S. prices and European prices, while strong, shows the effects of transportation costs, as well as some differences in product, due perhaps to differences in the quality of the nuts coming from California, or the different end uses to which different sizes and varieties are put.

One can also examine the problem from the point of view of the supplier: could one have profited *ex-post* from moving almonds from one purchasing market to another? The latter question is important for a simulation model: if the answer is negative, then we can assert a "Law of One Price" (LOP) which eases solution of the model and is characteristic of a single efficient world market for almonds. Therefore, in Table 5.4, we compute the correlation coefficients among the unit values of imports into the principal importing countries and, in the lower half of the table, the correlation coefficients among the logarithmic differences of those variables. The data in Table 5.4 suggest a highly efficient market in almonds across these countries. We weaken this conclusion only slightly for Italy: Italian import prices are highly correlated with the prices paid for imports in other countries (the top panel of Table 5.4) although the relative changes in import prices (bottom panel of the table) are somewhat more weakly correlated with prices in other countries. The main difference between the Italian series and the earlier import price series comes during the late 1960's, when the average import price in Italy fell sharply while other prices increased. We suspect that this reflects some transitory effect of

Table 5.3: Correlations among Average Annual Export Prices, 1961–89

	px^{SPA}	px^{ITA}	px^{USA}
px^{SPA}	1.00000		
px^{ITA}	0.99055	1.00000	
px^{USA}	0.95892	0.93633	1.00000

	$ld\,px^{SPA}$	$ld\,px^{ITA}$	$ld\,px^{USA}$
$ld\,px^{SPA}$	1.00000		
$ld\,px^{ITA}$	0.92000	1.00000	
$ld\,px^{USA}$	0.84761	0.83648	1.00000

Note: px^j is the average value of exports for country j, F.O.B. shipping port, calculated as the total value of exports divided by physical volume of exports. $ld\,px^j$ is the log difference in px^j, equal to the percent changes in the series from year to year.

the change in the industry that was then taking place, as Italian sales fell and the California industry expanded. Since 1970, there is no evidence that Italian prices behave independently of those elsewhere.

To complement the correlation analysis of prices, we carried out a detailed technical analysis of the interdependence of different price series, using unit-root and Dickey-Fuller tests for co-integration. Appendix A contains details of this investigation, which considers whether or not various pairs of price series can be statistically independent. For most pairs of price series, the hypothesis of independence is strongly rejected in favor of the hypothesis that the series are linked by a linear transformation, which is the form that the Law of One Price takes with transportation costs and quality differences. In particular, the analysis suggests that U.S. farmgate prices, which are used in this chapter's demand analysis and in the simulations of Chapters 6 and 7, are linked with foreign import prices by a linear rule. There is, however, some persistent independent movement of U.S. average export prices and foreign import prices, a result that is consistent with the results in the correlation analysis discussed above.

5.6 Notes on the Econometric Specification

The previous section presents the econometric results that make up a full description of the world almond market. Together with the Law of One Price rules linking the prices in various countries, discussed above and explicitly estimated in Chapter 6, the equations for consumption demand in the eight large markets described there, for storage demand in the United States, and for market-clearing ROW demand, are sufficient to determine prices and quantities for almond transactions in the principal markets, given almond harvests and macroeconomic conditions. Before applying these results in a simulation model, we produce some additional evidence for the plausibility of these econometric estimates. First, we present some additional demand equations, for the largest Rest-of-World countries. As these detailed estimates are broadly consistent with the estimated market-clearing ROW equation,

Table 5.4: Correlations among Annual Average Import Prices, 1961–89

	pm^{DEU}	pm^{FRA}	pm^{NLD}	pm^{GBR}	pm^{ITA}	pm^{JPN}
pm^{DEU}	1.00000					
pm^{FRA}	0.99233	1.00000				
pm^{NLD}	0.99249	0.99245	1.00000			
pm^{GBR}	0.98500	0.97133	0.97369	1.00000		
pm^{ITA}	0.96447	0.96810	0.95886	0.95126	1.00000	
pm^{JPN}	0.96630	0.94946	0.95845	0.98707	0.93665	1.00000
	$ld\,pm^{DEU}$	$ld\,pm^{FRA}$	$ld\,pm^{NLD}$	$ld\,pm^{GBR}$	$ld\,pm^{ITA}$	$ld\,pm^{JPN}$
$ld\,pm^{DEU}$	1.00000					
$ld\,pm^{FRA}$	0.95027	1.00000				
$ld\,pm^{NLD}$	0.95930	0.95440	1.00000			
$ld\,pm^{GBR}$	0.93002	0.83681	0.85408	1.00000		
$ld\,pm^{ITA}$	0.67204	0.69202	0.66310	0.60516	1.00000	
$ld\,pm^{JPN}$	0.88825	0.83580	0.81890	0.91419	0.54098	1.00000

Note: pm^j is the average value of imports for country j, C.I.F. importing port, calculated as the total value of imports divided by physical volume of imports. $ld\,pm^j$ is the log difference in pm^j, equal to the percent changes in the series from year to year.

from Table 5.2, we find these estimates to be supportive of the earlier aggregative estimate. In addition, these results are consistent with the individual demand functions that are included in the full simulation model. Second, we consider explicitly the specification of demands used here. In particular, we examine the hypothesis that quantities are fixed in the individual countries, in which case the correct specification would treat price as the dependent variable. We find no statistical evidence to support such a specification. These tests support the use of models in which prices are statistically and economically exogenous to individual countries. Finally, we present the results of model validation exercises that compare actual values to those predicted by the regression equations, both within-sample and for two out-of-sample years.

Demand Estimates: Medium-Sized Countries

In Table 5.5, we present the principal results from our estimates of almond demands in eight medium-sized countries. These countries represent the bulk of almond demand outside the major countries analyzed earlier. Since 1979, net imports (plus Australian harvests) in these countries have been on average 99 percent of the constructed ROW demand.[14] With the exception of Australia, these countries are all within the closely integrated region of Western Europe, in which Spanish, Italian, and Californian almonds compete most directly. These demand estimates therefore represent a disaggregation of the ROW demand which is constructed to clear the principal world markets of almonds.

These demand estimates were developed following the same procedures as for

[14]The sum of medium-country demands is not expected to be identical to calculated ROW demand. Almonds are imported by other countries—India, for example, imports significant quantities of California almonds—and there are other exporting countries, such as Chile, China, and the North African countries.

Table 5.5: Almond Demand in Medium-Sized Countries, Regression Results

Country	Almond Price	Income	Filbert Price	Constant	$R^2(adj.)$	*D.W.*	Observations
Switzerland	-0.39246	0.26701	0.17814	8.6370	0.87	1.43	1961 73,
	(-4.89)	(2.30)	(1.17)	(13.22)			77 89
Sweden	-515.98	3.8273	—	14647.0	0.66	1.32	1979–89
	(-3.98)	(1.50)		(6.90)			
elasticities	-0.57	0.17					
Belgium	-0.3880	0.4589		6.6071	0.77	0.53	1961 89.
	(-3.27)	(4.06)		(5.02)			exc. 85, 86
Denmark	-63.844	26.037	69.711	-2292.3	0.90	1.72	1961 88.
	(-1.46)	(6.88)	(1.23)	(-1.26)			exc. 75, 89.
elasticities	-0.24	0.12					
Australia	-577.17	9.8263		2417.1	0.73	1.73	1966–83,
	(-2.82)	(2.00)		(2.56)			1987-89.
elasticities	-0.68	0.49					
Norway	-0.3580	0.6413	0.1981	5.8447	0.92	1.83	1961 89,
	(-4.40)	(8.34)	(2.22)	(10.70)			exc. 88.
Austria	-52.45	3.7314		2360.7	0.81	1.83	1961 88.
	(-3.69)	(3.16)		(1.99)			exc. 75.
elasticities	-0.77	0.86					

Notes: *t*-statistics are in parentheses below estimated coefficients. Estimated equations are double-log, except for Sweden, Denmark, Austria and Australia, for which elasticities at the means are shown below the *t*-statistics. Equations are for total demands, and use total private consumption expenditures for Income. Demands are for net imports, in pounds kernel-weight, except for Australia, which is net imports plus total harvests. Almond Price is the average price of almond imports for each country, in constant national-currency units per pound kernel weight. Filbert Price is also average price of imports, in constant national-currency units per pound.

the large-country estimates presented earlier: a number of specifications and functional forms were estimated, with special attention to the existence of substitution effects. Again, net imports of almonds was used as a measure of total purchases, except for Australia, for which harvests were included.[15] In contrast to the large countries, in these countries per-capita specifications performed less well than did estimates where total demand was the dependent variable. Linear demand functions were specified for Sweden, Denmark and Australia, while for the other countries a double-log specification was preferred.[16] The price variables are the unit values of imports, value of imports divided by volume of imports, converted using market exchange rates and the consumer price index into real (1985) national-currency units per pound (kernel-weight). The Income term is Domestic Consumption Expenditures, from the National Accounts, also deflated by the Consumer Price Index into real national-currency terms. Again, the equations were estimated in two passes. After the first pass, observations for which the actual value of the dependent variable differed from its fitted value by more than twice the standard error of the estimate were identified as outliers and excluded from a second estimation. For most countries the functions were estimated from 1961 through 1989, except for Sweden, which did not report almond trade separately from other nut trade prior to 1979, and Australia, for which the almond harvest series starts in 1966.

The estimates in Table 5.5 fit the data fairly well, with acceptable statistical properties, with the exception of Belgium, where a low Durbin-Watson statistic suggests misspecification.

In the medium-sized countries (which are listed in order of the size in 1989 of their apparent almond consumption), the estimated own-price elasticities are all between 0 and -1, in the inelastic range. As such, they are generally consistent with the estimated elasticity of the constructed market-clearing ROW demand. Estimated income elasticities were all significantly positive, while filbert-price effects were weak or non-existent—consistent with the weak cross-price effect in the ROW equation.

In addition to serving as a validation of the estimate of ROW demand, in the sense of providing independent confirmation of the parameters estimated for the constructed ROW demand, these estimates provide additional evidence for the conclusion, based on the major-country analyses described above, that the demand for almonds is inelastic with respect to price, and that substitution relationships are weak.

Exogeneity of Prices

We presented above nine equations that account for the bulk of world trade in almonds. It is reasonable to inquire whether one can safely treat prices as exogenous in these equations. Thurman (1986) has demonstrated that the question is subject to empirical investigation, and its answer has important implications for the validity of the parameter estimates. When price is statistically endogenous to a particular equation, OLS estimates of the demand parameters are inconsistent, and should differ from those provided by other estimators, which are consistent when price is endogenous. On the other hand, when prices are statistically exogenous, the OLS estimates are consistent and are efficient relative to all other consistent estimators. When the alternative estimator is also consistent, we can apply Hausman's test

[15] Australian harvests appear to be reliably measured, so that the analysis of Australian demand is analogous to the American analysis.

[16] Note that the constructed Rest of World series was explained better by a linear demand function than by the double-log specification, while both specifications were used for different component medium-sized countries. Since the ROW series is an accounting construct, rather than an aggregation of known members, there is no reason to expect any particular relationship between the equations for the individual countries equations and for the constructed aggregate.

(Hausman 1978) of the hypothesis that prices are, in fact, exogenous to each country.

For each of the equations reported above, we re-estimated the equations using a two-stage least-squares (2-SLS) estimator, where we included as exogenous variables the filbert price and the consumption series and real exchange rates for all of the countries. For each equation i, the vector

$$\hat{q}_i = \hat{\beta}_i - \tilde{\beta}_i$$

was formed, where $\hat{\beta}_i$ is the vector of coefficient estimates using OLS, and $\tilde{\beta}_i$ is the 2-SLS estimator. We then form the variance-covariance matrix of $\hat{q}_i$ as

$$\text{cov}\left(\hat{q}_i\right) = \text{cov}\left(\hat{\beta}_i\right) \text{cov}\left(\tilde{\beta}_i\right).$$

If price is exogenous in equation i, then the Hausman test statistic h_i is

$$h_i = \hat{q}_i' \left[\text{cov}\left(\hat{q}_i\right)\right]^{-1} \hat{q}_i \sim \chi^2_{K_i - 1},$$

where K_i is the number of explanatory variables in equation i.

The calculated Hausman test statistics h_i are listed in Table 5.6. Rejection of the hypothesis of exogenous prices requires that the statistic be in the right-hand tail of the χ^2 distribution: the coefficient estimates must differ significantly. In fact there was almost no difference between the OLS and the 2-SLS estimators, while the 2-SLS estimators are rather less precise. We conclude, then, that there are no statistical reasons for treating prices as endogenous. OLS is consistent and efficient.[17]

Model Validation

Table 5.7 contains the Root Mean Square Error (*RMSE*) and the Theil Inequality Coefficient (*TIE*) for both the within-sample fitted values and for the out-of-sample predictions for 1990 and 1991, as well as Theil's decomposition of *RMSE* for the within-sample fitted values.[18] Within sample, the equations fit very well, with *TIE* generally quite small, although the equations for ROW purchases and for storage demand fit a little less well. In all cases almost all of the *RMSE* is accounted for by the covariance portion: although the series of fitted values differ from the series of actual values, they are still highly correlated with actual values.

Out of sample, the *RMSE* are generally quite close to their within-sample values. However, as there is less variability in the short out-of-sample series (which is what determines the denominator of *TIE*), the *TIE* coefficients are considerably larger than their within-sample values. Nonetheless, they are generally small, with values below 0.4, with the exception of Germany (barely) and the equations for Italian imports and exports. With only two out-of-sample observations, Theil's decomposition is unstable and not useful.

Overall, the validation exercises indicate that the estimated models provide good estimates of the demand parameters, and can be useful in forecasting and policy-simulation exercises.

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[17] A similar analysis was performed where the filbert price was also treated as an endogenous variable. Given the absence of evidence for statistical simultaneity of almond prices and almond demands, and the relatively weak influence of filbert prices on almond demands, it is not surprising that there was no evidence that filbert prices were determined simultaneously with almond demands. The analysis was also attempted using a non-linear maximum-likelihood procedure using the set of double-log and linear demand equations, price equations of the form of (5.3), and adding-up restrictions; such a method is analogous to a three-stage least-squares procedure, except that it permits non-linear component equations. Unfortunately, it proved impossible to compute parameter estimates, as the system solution algorithm did not converge.

[18] The last section of Chapter 3 contains a derivation of the Theil decomposition and discussion of its interpretation.

Table 5.6: Hausman Test Statistics comparing OLS and 2-SLS Estimators, for Exogenous Almond Price

Equation	h_i	*d.f.*
United States 61–89	1.70	5
United States 70–89	0.98	5
Germany 61–89	2.32	4
Germany 70–89	0.05	4
France 61–89	1.76	5
France 70–89	1.51	6
Netherlands 61–89	4.18	5
Netherlands 70–89	0.90	5
Great Britain 70–89	0.71	3
Japan 62–89	0.10	2
Japan 70–89	0.13	2
Italy 61–89	0.39	4
Italy 70–89	0.02	2

Table 5.7: Within-Sample and Out-of-Sample Validation Statistics for Demand Equations

Country	*Estimation Period*	*RMSE*	*TIE*	U^B	U^V	U^C
Within-sample:						
United States	1961–89	0.123	0.016	0.000	0.007	0.993
Japan	1962–89	0.031	0.014	0.000	0.007	0.993
Canada	1961–89	1131.3	0.012	0.000	0.042	0.958
Great Britain	1970–89	0.033	0.011	0.000	0.035	0.965
Germany	1970–89	0.059	0.005	0.000	0.007	0.993
Netherlands	1961–89	0.049	0.006	0.000	0.022	0.978
France	1970–89	0.029	0.005	0.000	0.026	0.974
Italy: imports	1961–89	0.066	0.037	0.000	0.048	0.952
Italy: exports	1961–89	0.169	0.021	0.000	0.006	0.994
Rest-of-World	1970–89	9794.2	0.109	0.000	0.063	0.937
Storage	1972–89	19214.7	0.146	0.000	0.053	0.947
Out-of-sample:						
United States	1990–91	0.218	0.307			
Japan	1990–91	0.093	0.279			
Canada	1990–91	1152.2	0.368			
Great Britain	1990–91	0.097	0.276			
Germany	1990–91	0.041	0.402			
Netherlands	1990–91	0.041	0.187			
France	1990–91	0.046	0.293			
Italy: imports	1990–91	0.442	0.501			
Italy: exports	1990–91	0.291	0.547			
Rest-of-World	1990–91	61365.0	0.394			
Storage	1990–91	31470.8	0.163			

Notes: *RMSE* is Root Mean Square Error. *TIE* is the Theil Inequality Coefficient, a normalization of *RMSE*. U^B, U^V, and U^C are, respectively, the bias, variance, and covariance components of *RMSE*. All equations are double-log, except for equations for Canada, Rest-of-World, and Storage, which are linear. Since the *RMSE* decomposition is not well defined for two or less observations, it is omitted for the Out-of-Sample exercise.

6. A SIMULATION AND FORECASTING MODEL OF THE ALMOND INDUSTRY

6.1 Introduction

This chapter describes a full model of the almond industry, which simulates the evolution through time of the quantities of almonds purchased in the principal almond markets, the prices paid for almonds, and the acreage of almonds planted and removed in California. This model uses the econometric and statistical results described in previous chapters, including the work on yields described in Chapter 2, on plantings and removals in Chapter 3, and on final and storage demand and the linkages between prices in Chapter 5.

Figure 6.1 provides a schematic depiction of this model, with simultaneously-determined variables in solid boxes, exogenous or predetermined variables in dotted boxes, and lags indicated by dashed lines. In a given year, the available supply has three components: California harvest H_t, which is the product of bearing acreage BA_t and per-acre yield y_t, Spanish net exports NX_t^{SP}, and inventories carried over from the previous year, S_{t-1}.[1] This supply interacts with the various demands for current almonds, including U.S. and foreign final demands and demand for stocks carried out at the end of the year, to determine the California farm price for almonds.[2] Foreign prices in the model are determined from the California farm price by adjusting the California price for marketing and transportation costs and exchange rates. This interaction is depicted in the lower half of Figure 6.1. Foreign demands are determined by these prices and by exogenous variables. Based on the work reported in Chapter 4, one might also describe foreign supplies as being influenced by current prices. However, since it has proved impossible to find a strong relationship between prices and Spanish net exports, in this chapter Spanish supplies are treated as exogenous. However, in the longer-term policy analyses of Chapter 7, the estimated linkage between prices and Spanish acreage is used.

The top half of Figure 6.1 depicts the way in which current year profits influence future California plantings and removals decisions through the supply-response models, in this way determining future harvests. This interaction between current prices and profits and future supplies represents the key dynamic linkage in the simulation model.

The rest of this chapter is devoted to a detailed exposition of the components and functioning of the simulation model, including various validation exercises. Its application for forecasting and policy analysis is described in Chapter 7.

6.2 Determination of Prices and Quantities

The Linearized Demand Equations

While the estimated demand equations in Chapter 5 are useful for generating point estimates of elasticities, and indicating the determinants of per-capita demand, they cannot be used directly for any policy-optimization exercise. With the exception of the Rest-of-World equation all demand equations are estimated in double-log form. So long as complete supply response is not immediate, the optimal policy implied by these constant-elasticity demands, with inelastic demand, is to sell an

[1]One might also consider Italian net exports as part of world supply. However, since we have analyzed both Italian exports and Italian imports as functions of price, and since Italy is now a net importer of almonds, we describe these components as part of world demand for almonds.

[2]This single-price model of the industry assumes that growers and handlers possess similar information about expected final demands. It should be noted that growers typically precommit part of their crops before harvest, and sell other parts of the crop on a consignment basis; thus, there is no sharp distinction between the information incorporated in the ex-post farmgate price and expected final demands evaluated at different points in time throughout the season.

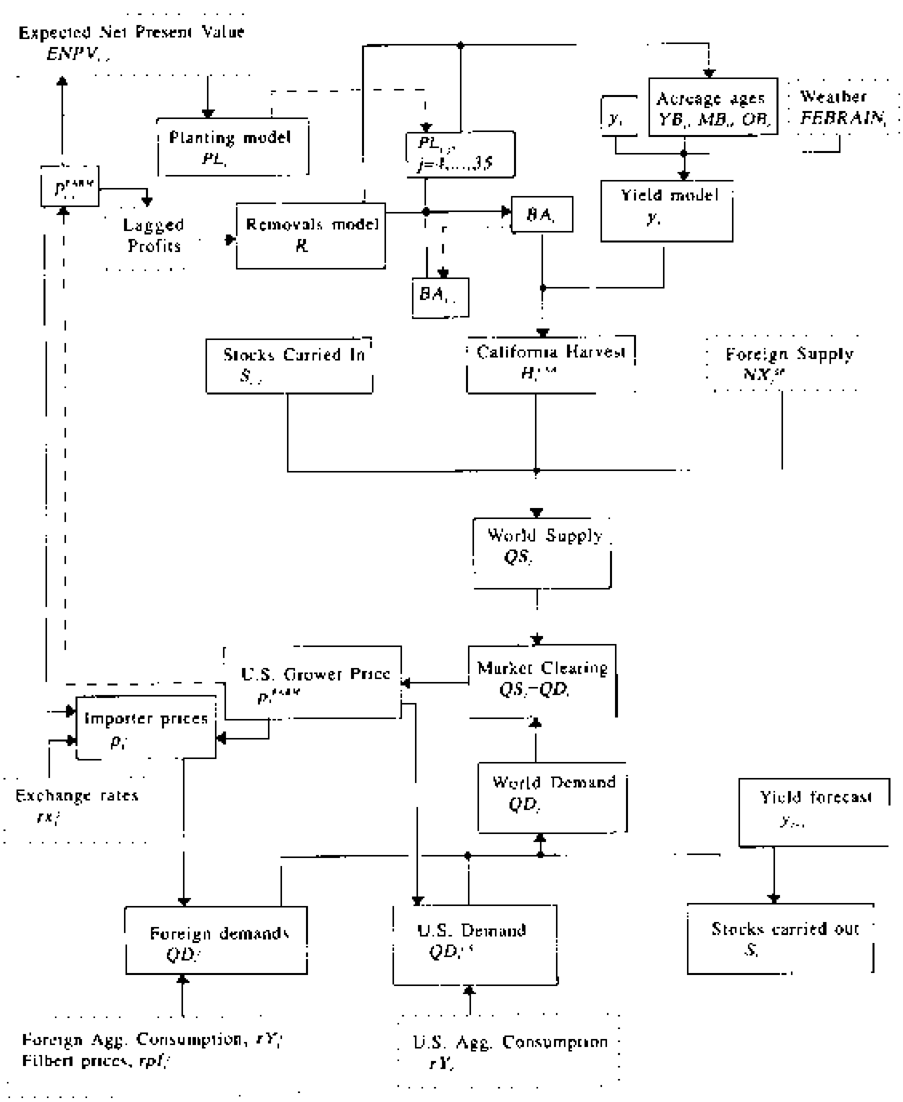

Figure 6.1: Flowchart for the Simulation Model

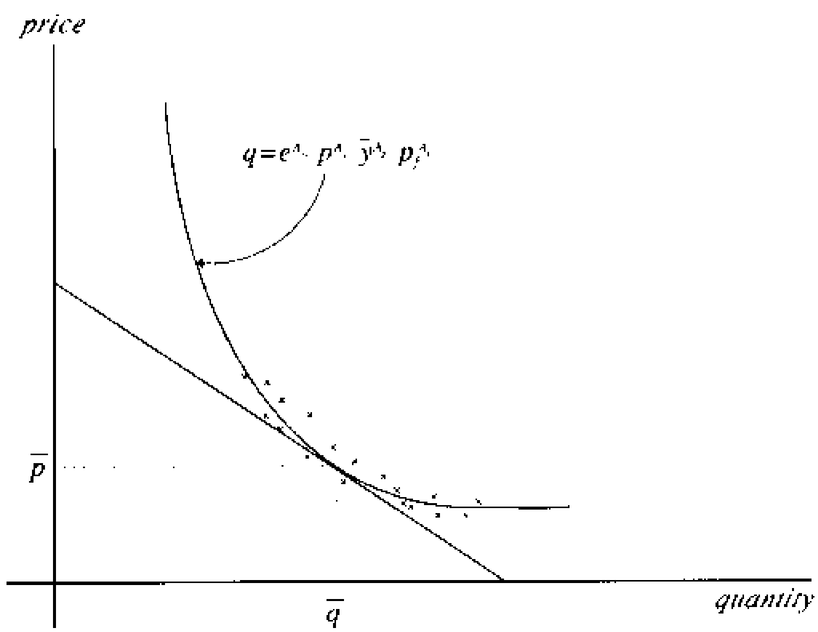

Figure 6.2: Linearizing the Constant-Elasticity Estimated Demand

infinitesimally small quantity, earn infinitely large profits immediately, and then let the long run take care of itself. The problem is that while the constant-elasticity demand specification may provide a better statistical approximation to the data than other models used, for the range of values of prices and quantities actually observed, it is unlikely to hold when we extrapolate outside the range of the sample data—especially for small quantities and high prices. In order to use our demand estimates for policy work, we must transform them so that they become more useful at the values that a policy optimization will suggest.

In the model described here, and applied in Chapter 7, we interpret the elasticity estimates from Chapter 5 as good approximations of the elasticities of demand at the mean values of all the variables. However, for simulation purposes we assume that demand is approximately linear in the relevant range. In Figure 6.2, the curved line traces the estimated constant-elasticity demand function at mean values of the exogenous variables, passing near the points representing observations (adjusted using the regression parameter estimates for variations in the exogenous variables). We use in the simulation model a line that is parallel to the regression curve at the mean values of price and quantity, where the mean is calculated over the period 1970-89. Thus, the linearized approximation passes through the arithmetic mean of the sample data, while the statistical model passes through their geometric mean.

Consider a typical equation. The double-log regression estimates give the parameters $A_0, \ldots, A_3$ for the demand function

$$q = f(p, y, p_f) = e^{A_0} p^{A_1} y^{A_2} p_f^{A_3}. \tag{6.1}$$

Since the estimated parameters $\hat{A}_1$, $\hat{A}_2$, and $\hat{A}_3$ in this form are the estimated elasticities, the linearization through the mean of (6.1) is

$$q = \alpha_0 + \alpha_1 p + \alpha_2 y + \alpha_3 p_f. \tag{6.2}$$

Table 6.1: Linearized Demand Coefficients

Country	α_0	α_1	α_2	α_3
United States	0.819	-0.713	8.283	–
Germany	-0.0937	-0.169	0.118	0.112
France	0.739	-0.0309	0.535	0.00698
Netherlands	0.676	-0.0895	1.50	0.0579
Great Britain	0.463	-0.206	0.0442	·
Japan	-0.0938	-2.07×10^4	3.01×10^4	—
Canada	-1918	-3800	61.5	6605
Italy imports	0.192	-9.53×10^6	0.0391	-8.19×10^6
Italy—exports	-0.596	1.86×10^5	·	2.16×10^5
Rest of World	-16389	-11215	108	3441

Notes: α_0 is the constant in the linearized function. α_1 is is the almond-price coefficient. α_2 is the coefficient on per-capita (except for Canada and Rest of World) real domestic consumption expenditures. α_3 is the filbert price coefficient, except for the Italian import and export equations, where it is the coefficient on Italian harvests. All almond prices are average price of imports in real national-currency units per pound kernel weight (1985 prices), except for U.S., which is real farmgate price, and Rest of World, which is real German import price. Filbert prices are conversions to real national-currency units per pound of average price of German imports (in constant Deutschmark for Germany and Rest of World), except for Canada, which is average price of Canadian imports. All equations except Canada and Rest of World are for pounds (kernel weight) per capita; Canada and Rest of World are in thousands of pounds (kernel weight).

where

$$\alpha_1 = \hat{A}_1\frac{\bar{q}}{\bar{p}},\ \alpha_2 = \hat{A}_2\frac{\bar{q}}{\bar{y}},\ \alpha_3 = \hat{A}_3\frac{\bar{q}}{\bar{p}_f}$$

and

$$\begin{aligned}\alpha_0 &= \bar{q} - \alpha_1\bar{p} - \alpha_2\bar{y} - \alpha_3\bar{p}_f \\ &= \bar{q} - \left(1 - \hat{A}_1 - \hat{A}_2 - \hat{A}_3\right).\end{aligned}$$

If the regression equation excludes the filbert-price term, then $\hat{A}_3 = \alpha_3 = 0$. The Italian import and export equations were linearized in an analogous fashion. To account for the excluded observations in the regression equations, dummy parameters were calculated to force the linearized form through the observation for those years. The parameters of the linearized demand functions are shown in Table 6.1.

Price Rules

We assume that nominal prices in two countries can differ, once they have been converted to a common currency, only by an amount that is constant in real terms, representing the difference in costs of bringing almonds to market in the two countries (including transportation and marketing costs). That is, if there are J countries, D_{1t} is the price deflator for country 1 in year t, X_{jt} is the market exchange rate for year t (units of country j currency per units of country 1 currency), andP_{jt}

is the nominal price of almonds in country j, $j = 1, \ldots, J$, then we assert that

$$P_{1t} - \frac{P_{jt}}{X_{jt}} = D_{1t} \cdot c_j, \; j = 2, \ldots, J, \tag{6.3}$$

where c_j is the constant real differential between country 1 and country j prices. In our demand functions, we deflate nominal almond prices by the consumer price index. Therefore, using the country 1 CPI as the deflator for c_j, equation (6.3) becomes

$$\begin{aligned} c_j &= \frac{P_{1t}}{CPI_{1t}} - \frac{CPI_{jt}}{X_{jt}CPI_{1t}} \frac{P_{jt}}{CPI_{jt}} \\ &= p_{1t} - \frac{1}{x_{jt}} p_{jt}, \; j = 2, \ldots, J, \end{aligned}$$

where $x_{jt} = X_{jt}CPI_{1t}/CPI_{jt}$ is the real exchange rate that converts constant units of country 1 currency into constant units of country j currency. This is rearranged to give $J - 1$ prices in terms of the country 1 price:

$$p_{jt} = x_{jt} \left(p_{1t} + c_j \right), \; j = 1, \ldots, J.$$

In our statistical work, we have calculated U.S. demand using crop-year harvest and inventory data. We found that this demand was best explained by the crop-year farmgate price, which is the value of nuts delivered by growers to handlers, divided by the volume of deliveries, for nuts harvested in year t. However, a substantial portion of the year t harvest is actually sold in year $t + 1$. As exports are clustered at the beginning and end of the calendar year, the calendar-year import data reflect approximately equal quantities of current and previous crop-year data. When the U.S. farmgate price is selected as the numeraire in the price rules, both its current and lagged values must be included. Since regressions of real-dollar foreign import prices on lagged and current farmgate prices yielded positive constants and price coefficients that were similar and close to .5, we imposed an equal-weight combination, so that

$$p_{jt} = x_{jt} \left(0.5 \cdot p_{1t} + 0.5 \cdot p_{1,t-1} + c_j \right), \; j = 1, \ldots, J. \tag{6.4}$$

The average markups c_j, calculated as

$$c_j = \frac{1}{20} \sum_{t=70}^{89} \left(\frac{p_{jt}}{x_{jt}} - 0.5 \left[p_{1t} + p_{1,t-1} \right] \right),$$

are shown in Table 6.2.

Solution with Known Yield, Acreage, and Spanish Net Exports

If U.S. yields and acreage and Spanish net exports are known (as, for example, when the model is used for a within-sample simulation of prices and quantities), the storage equation (5.8) describes carryout inventory demand S_{t+1}. We impose an equilibrium condition,

$$\begin{aligned} S_t + y_t^{CA} BA_t + nx_t^{SP} &= pop_t^{US} q_t^{US} + pop_t^{DEU} q_t^{DEU} + pop_t^{FRA} q_t^{FRA} + \\ & \quad pop_t^{NLD} q_t^{NLD} + pop_t^{GBR} q_t^{GBR} + pop_t^{JPN} q_t^{JPN} + \\ & \quad pop_t^{ITA} \left(imp_t^{ITA} - exp_t^{ITA} \right) + \\ & \quad Q_t^{CAN} + Q_t^{ROW} + S_{t+1}. \end{aligned} \tag{6.5}$$

The left-hand side of (6.5) is marketable supplies in year t, composed of inventories carried over from the previous year, plus California harvests (handler receipts), plus

Table 6.2: Average Real Markup of Import Prices over U.S. Farmgate Price, in 1985 Dollars per Pound (Kernel Weight)

Country	c_j
Germany	0.447
France	0.502
Netherlands	0.558
Great Britain	0.411
Japan	0.561
Canada	0.488
Italy	0.472

Spanish net exports. The right hand side is the various dispositions of the supply: population times per-capita consumption for the United States, Japan, and the large European importers, population times per-capita net imports for Italy, total demands for Canada and Rest-of-World, with otherwise-unsold supplies carried over as stocks to the next year.

Equations (5.8) and (6.5), together with the 10 linear demand functions of Table 6.1 and the 7 price rules (6.4), using the markup parameters c_j of Table 6.2, form a system of 19 equations, which can be solved for 10 country demands, carryout inventory S_{t+1}, 7 import prices, and the U.S. farmgate price.

6.3 Plantings and Removals: the Long-Run Model

In the short run, almond supplies are determined by a combination of the earlier investment decisions that determine bearing acreage, by the size of the stock of almonds unsold at the end of the previous year, and by yield, which in turn is determined by weather, the age of the almond acreage, and the current state of the alternate-bearing cycle. There is no contemporaneous influence of price upon supplies. Price is therefore, in the short run, determined on the demand-side of the model: price adjusts to clear the demands. There is, however, a long-run response of supply to price. Potential or existing growers observe prices and costs, and decide whether an expansion of almond acreage will be profitable, in which case they plant additional acreage in almond orchards, or whether their land would find more profitable use under a different crop, in which case orchards will be removed. In Chapter 3 we discussed the models which best described these planting and removal decisions. Here we discuss briefly how these models are combined with the short-run demand-clearing model to form a long-run model to determine acreage, price, and consumption in the almond industry.

The Plantings and Removals Equations

The plantings model, described in Chapter 3 as equation (3.16), uses the expected net (after tax) present value per acre of an orchard in year $t-1$, $ENPV_{t-1}$, plus the previous year's plantings, PL_{t-1}, to predict plantings in year t, PL_t, measured in thousands of acres. The plantings model is

$$PL_t = 3.2120 + 0.0058\ ENPV_{t-1} + 0.5810\ PL_{t-1}.$$

where $ENPV_t$ is calculated by applying the year t deflated price to a yield curve to get an expected time profile of orchard gross receipts.[3] Year t costs are then subtracted to get a gross margin, which is reduced by the estimated year t marginal tax rate. The ENPV calculations also take account of the costs of establishing the orchard, any investment tax credit, and depreciation deductions. The cash flow, including sales, growing costs, establishment costs, and tax benefits, is then capitalized to year t using the current real interest rate. In the simulations, we used the price generated by the single-period model to generate the ENPV of an orchard for that year. $ENPV_t$ is then used to simulate plantings for year $t+1$.

The removals model, discussed in Chapter 3 as equation (3.17) uses the per-acre operating margin π_t (price times yield minus production cost, after tax, in real terms) for the past four years, as well as actual last-period acreage and a set of dummy variables to account for changes in tax laws. The estimated equation is

$$\begin{aligned} R_t \; = \; & 5398.8 - 5.184\ \pi_{t-1} - 7.8458\ \pi_{t-2} - 13.831\ \pi_{t-3} - 2.8431\ \pi_{t-4} \\ & + 0.0044\ K_{t-1} - 2335.6\ D70_t + 28.375\ D76_t + 738.4\ D82_t \end{aligned}$$

where R_t is removals out of the $t-1$ bearing acreage, K_{t-1} is total acreage in year $t-1$, and the three 0-1 dummies take the value 0 for all years except 1970–1975 for $D70_t$, 1976-1981 for $D76_t$, and 1982–1990 for $D82_t$. Again, we use the price generated by the single-period market-clearing solution to calculate past values of profitability, which are then used to simulate removals.

The Evolution of the Age Structure of California Orchards

In estimating the yield model, the age structure of trees was built up from time-series of plantings and of bearing acreage. If plantings and bearing acreage are known, then one can calculate acreage removals as

$$R_t = PL_{t-4} - (B_t - B_{t-1}),$$

where B_t, PL_t, and R_t are, respectively, bearing acreage, plantings, and removals in year t. Year t removals are thus taken out of year $t-1$ bearing acreage, as discussed in section 3.5. In the simulation model, data on B_t are no longer available, but we can use the plantings and removals models to generate simulated values of B_t, as well as of the age shares used in the yield model. Designating simulated values with a caret, we calculate

$$\hat{B}_t = \hat{B}_{t-1} + \widehat{PL}_{t-4} - \hat{R}_t,$$

where the values of plantings and removals are given by substituting simulated prices into the calculations of expected net present value, in the planting equation, and per-acre profitability, in the removals equation.

The simulated age distributions are then constructed by summing plantings of various ages for young and mature bearing-acreage, and by subtracting the young and mature acreage from total bearing-acreage to calculate old acreage. This is equivalent to assuming that all removals are from the stock of old trees. These equations are:

$$\widehat{YB}_t = \sum_{\tau=4}^{8} \widehat{PL}_{t-\tau}, \quad \widehat{MB}_t = \sum_{\tau=9}^{40} \widehat{PL}_{t-\tau}, \quad \widehat{OB}_t = \hat{B}_t - \widehat{YB}_t - \widehat{MB}_t$$

[3] Presumably incorporating a more sophisticated expectations-generating scheme than simply looking at the current price would improve the performance of the simulation model.

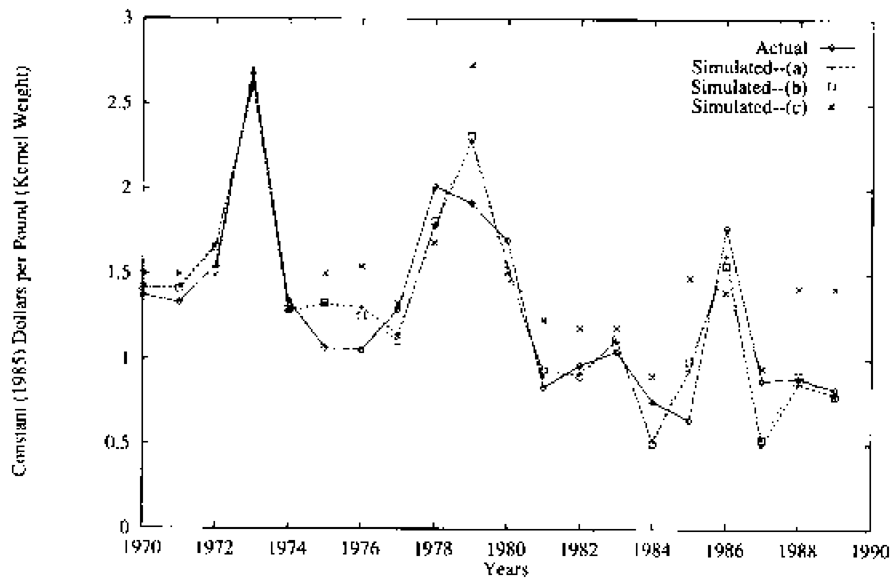

Figure 6.3: Real U.S. Farmgate Price, Actual and Simulated (with actual plantings)

6.4 Within-Sample Simulation Exercises

Price-and-Quantity Simulation with Actual Acreage

The core of the within-sample simulations is the set of simultaneous equations that determine prices and demands for each period, for given harvests, inventories, yields, and the U.S. farmgate price in the previous year (since the foreign prices are a markup over the average of current and lagged U.S. (crop year) farmgate price). The simplest simulation, which helps show how well the simultaneous core represents the real supply and demand system, uses actual values for all of these predetermined variables. The prices for this simulation are plotted in Figure 6.3 as Simulated–(a). Next, in Simulated–(b), we use the simulated value of carryout in year t for carryin in year $t+1$, rather than the actual value. In Simulated–(c), we use actual values of plantings and removals to construct tree-age distributions and actual values of the rainfall variable to simulate yield within the model. This simulated yield is then used instead of actual yields with actual bearing acreage to simulate harvests, and is also used for the future-yield terms in the carry-out storage equation.

To evaluate the simulation model's performance, we plot the model's predictions of U.S. farmgate price. This price is the key variable linking the various components of the model: through the markup equations it determines foreign demand, it is the price used in the U.S. demand equation, and it is the endogenous variable in the acreage-determining models. If the model cannot adequately simulate the evolution of prices, it cannot simulate any of the other endogenous variables either.

All three simulations track the large movements in almond prices fairly well. As one would expect, the larger is the number of variables being simulated, the less accurate is the simulation. It is worth noting, however, that replacing actual inventory carry-in by values from the simulation (Simulated–(b)) changes the price simulation very little. This suggests that, whatever the weaknesses of the storage

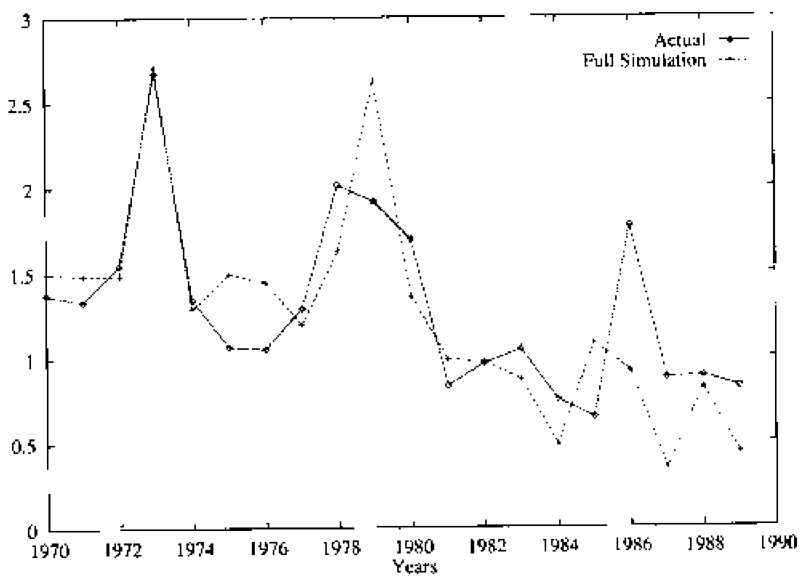

Figure 6.4: Real U.S. Farmgate Price, Actual and Full Simulation

model, it does not make a major contribution to the full model's error. Error in the yield model is far more important. This outcome is not surprising: in a model with inelastic demands, small changes in quantities transacted are associated with large changes in prices.

Full Simulation: Acreage, Quantities, and Price Endogenous

The most difficult within-sample simulation relies on no external information concerning the almond industry: all prices, plantings, removals, inventories, and consumption are determined within the model (although pre-1970 plantings use actual values). This simulation, for which the values of the real U.S. farmgate price are plotted in Figure 6.4, differs from those discussed above in that the plantings and removals models are used to generate bearing acreage and the age distributions used in the yield model. It should be recognized that errors in the full simulation are cumulative: overpredicting plantings in one year leads to a persistently high bearing-acreage and harvest value. There is, therefore, an opportunity for the model's predictions to diverge from historical experience.

The full simulation model was validated using the evaluation procedures described in section 3.7. The identification of "within sample" and "out of sample" is a little problematic, as the underlying demand equations were estimated over the periods 1961-1989 and 1970–89, depending on the country, while the plantings and removals equations were estimated over 1961-90. Since the plantings and removals equations use lagged prices, which are determined on the demand side of the model, we have identified 1990 as "out of sample" for the entire model. This has the benefit of making available three observations for the out-of-sample validation, which is necessary if one is to reliably decompose the mean squared error.

The validation statistics are shown in Table 6.3. Within sample, the model performs very well, with *TIE* close to zero, and (with the possible exception of the removals simulation) little evidence of bias. In all cases over 85 percent of the error

Table 6.3: Validation Statistics for Full Simulation Model

Country	*Estimation Period*	*RMSE*	*TIE*	U^b	U^v	U^c
Within-sample:						
World Demand	1970–89	115719.4	0.014	0.030	0.111	0.859
U.S. Real Farmgate Price	1970–89	0.319	0.029	0.011	0.073	0.916
U.S. Harvests	1970–89	90311.4	0.025	0.037	0.109	0.854
U.S. Plantings	1970–89	8571.3	0.047	0.037	0.041	0.922
U.S. Removals	1970–89	3970.5	0.068	0.139	0.002	0.859
Out-of-sample:						
World Demand	1990-92	144649.3	0.21	0.510	0.178	0.312
U.S. Real Farmgate Price	1990-92	0.398	0.42	0.182	0.117	0.701
U.S. Harvests	1990-92	112889.2	0.36	0.627	0.174	0.198
U.S. Plantings	1990-92	10714.1	0.68	0.636	0.065	0.299
U.S. Removals	1990-92	4963.1	0.99	0.700	0.003	0.297

Notes: *RMSE* is Root Mean Square Error. *TIE* is the Theil Inequality Coefficient, a normalization of *RMSE*. U^b, U^v, and U^c are, respectively, the bias, variance, and covariance components of *RMSE*. The validation statistics are calculated by comparing the values from the full simulation model to actual values. Note that the values for 1990 are treated as "Out of Sample" for Plantings and Removals even though the regression estimation period included 1990; as the demand side is estimated only through 1989 the price simulation for this year is truly out-of-sample.

in the series is in the "covariance" component U^C, a desirable outcome. Of the five series, the simulation of U.S. removals is weakest, with the highest *TIE* and with the most evidence of bias.

Out of sample the performance of the model is, not surprisingly, weaker. In particular, the *TIE* for the removals equation is close to its highest possible value. We attribute this to corrections in the data series made following the 1992 tree census: the acreage was smaller than had been indicated by the CASS intercensal accounting, suggesting that removals had been under-reported for a number of years; the correction was made by showing high removals for 1992. This compounded the poor performance that we expected from the weakest link in the simulation model. We note higher root mean square errors for all of the other simulated series as well, and a resulting elevation of the *TIE* statistics. We are encouraged, however, by the decomposition of the *RMSE* in the case of the critical U.S. farmgate price, with evidence that this key variable's simulation is unbiased and prone to match the turning points of the series of actual values.

Finally, we argue that since in the "within sample" simulation the U.S. supply is entirely endogenous, with only weather and exogenous variables coming from outside the model, the strong within-sample performance of the model earns more weight than in the case of a simple regression fit. That after 20 years of simulated plantings and removals the model still generates prices close to those actually observed, as seen both in Figure 6.4 and in Table 6.3, is a strong argument for the utility of this model for simulating the effects of changing policies in the almond industry.

7. RESERVE POLICY ANALYSIS

7.1 Introduction

This chapter discusses marketing orders and reserve policy and analyzes almond market response to specific types of reserve strategies. Results from two economic models are reported and analyzed. First, in Section 7.2 the econometric model described in Chapter 6 is used to simulate market behavior over the period 1993–2010 under policies of no reserve or a reserve that maximizes California almond industry revenues in each year, given the projected California harvest. Because reserves are set after the harvest, current almond production costs are sunk and, thus, irrelevant for reserve decision-making purposes. Therefore, the revenue-maximizing reserve is also the short-run profit-maximizing reserve.

Results from this analysis illustrate a short- vs. long-run tradeoff from marketing order policy: industry actions taken to raise short-run profits tend to be detrimental in the long run because they stimulate entry and expanded production. We therefore develop a dynamic optimization model that incorporates this tradeoff and, for a given set of market parameters, derive the trajectory of reserve strategies that is optimal over a discounted 50-year horizon. This model is discussed in Section 7.3, and results based on the model are presented in Section 7.4.

The Almond Board has authority to set, with the concurrence of the Secretary of Agriculture, both allocated and nonallocated reserves. Allocated reserves divert almonds permanently from primary consuming markets to secondary markets such as oils, animal feed, or disposal. Nonallocated reserves temporarily restrict the flow of almonds to the market at specific points in time. A percentage of the crop may be withheld at harvest and released at intervals over the marketing season, or it may be withheld over the entire season and released into the next crop year.

Our analysis of reserve policy focuses on allocated reserve strategies. Nonallocated reserve policy was not studied in detail for two reasons. First, the demand, supply response, yield, and storage equations that are used in the econometric and optimization models are based on annual data. The unit of observation is the crop year. The models are not equipped to handle intra-year storage decisions that determine availability of almonds at different times within a year.

Second, the econometric model can simulate the impact of inter-year storage decisions that determine the availability of almonds between years. However, our view is that the private market usually has incentives to undertake the optimal amount of both intra- and inter-year storage of almonds. To elaborate briefly on this point, storage from time t_1 to time t_2 is profitable if the expected increase in price exceeds the physical storage costs plus opportunity costs of holding almonds for this period. However, if storage is profitable to undertake, private traders and handlers normally have proper incentives to undertake the correct amount of storage independent of mandates from the almond board. Thus, these decisions are usually best left to market forces and we focus our analysis on allocated reserve policy.[1]

The approach developed in this chapter to modelling marketing order behavior generally, and allocated reserve policy specifically, departs from traditional approaches exemplified in the work of Minami, French, and King (1979), French and

[1] An alternative statement of this conclusion is that there are usually no externalities associated with the storage decision and, thus, no basis for collective action. A possible exception to this conclusion occurs when the cumulative effect of individual storage decisions results in a "stockout" situation, so that no almonds are available to key users for a period of time. These users may respond by permanently replacing almonds with other ingredients in their recipes, thereby foreclosing a market outlet to the industry. We discount the practical significance of this phenomenon for two reasons: first, the demand analysis conducted in this study revealed generally limited substitution for almonds. Second, stockouts are likely to occur in tight-supply years, so reserve policy to guard against this occurrence would, paradoxically, call for assignment of a nonallocated reserve when supplies are low and prices are relatively high.

Nuckton (1991), and others. The traditional approach models decisions made under marketing order authority as general functions of exogenous variables affecting the industry. For example, French and Nuckton express the tonnage of raisins marketed under authority of the Raisin Administrative Committee (RAC) as a function of current period raisin deliveries plus carry in from packers and the reserve pool, the packer price for raisins lagged one period, and domestic movement of raisins lagged one period. Such a formulation arises from a rather literal interpretation of the objectives of marketing orders as stated in the original enabling legislation and of the factors mandated in specific marketing order statutes to guide volume allocation decisions.

Federal marketing orders were authorized under the Agricultural Marketing Agreement Act (AMAA) of 1937, with several states enacting parallel legislation near this same time authorizing state-level marketing orders. The stated policies of the AMAA as they pertain to volume regulations are to (*i*) establish "parity" prices for farmers, (*ii*) protect consumer interests, and (*iii*) provide for the orderly flow of product to market by avoiding "unreasonable fluctuations in supplies and prices." The Raisin Marketing Order studied by French and Nuckton (1991) lists nine factors to be considered by the RAC in making volume recommendations to the Secretary of Agriculture. These include (*i*) the estimated carry in, (*ii*) estimated current year production, (*iii*) domestic and world demand, (*iv*) desired carryover tonnage, and (*v*) current and predicted raisin prices to producers and handlers. Similarly the Almond Marketing Order specifies that volume control decisions be based on "the ratio of estimated trade demand... less the handler [carry in]... plus the desirable handler carryover... to the estimated production of marketable almonds (§981.47)." The link from the actual marketing order language to model specifications such as French and Nuckton (1991) is, thus, clear.

However, from a modeling perspective, it is desirable to specify the behavior of these industry decision-making bodies within an optimization framework. Although the AMAA specifies multiple objectives, including attention to consumer interests, the fact remains that decision making in marketing orders is in the hands of boards comprised exclusively of growers and marketers of the affected commodity.[2] Consumer interests will be considered, if at all, by the Secretary of Agriculture in his oversight capacity. Given then that effective control of marketing orders is in the hands of producers and marketers, it is logical to assume that this group will act in its self interest, i.e., it will seek to maximize in some form the profits accruing to the industry. Within the framework of industrial organization, an industry operating under a marketing order is modeled as an industry cartel. We develop this framework in the subsequent sections of this chapter. As noted, this approach departs from tradition, but antecedents can be found in the work of Kimmel (1987) and Cave and Salant (1995).

7.2 Reserve Policy I: No Reserve vs. a Static Profit-Maximizing Reserve

Model 1 was used to simulate the impacts of two alternative baseline policies, no reserve, and a reserve that maximizes industry revenues for each year. These simulations incorporate the world demand models and U.S. supply conditions discussed earlier in this monograph.[3] They also incorporate conditions facing the industry in 1993 for exogenous variables including production costs, income and population in

[2]For example, the Almond Board of California consists of 10 members, with membership divided equally between growers and handlers.

[3]Because the econometric model is intended primarily for short-term forecasts and simulations, Spanish exports are given exogenously in this model and are set at 55.5 million lbs., which corresponds to actual exports for 1989, considered to be a normal marketing year for Spain.

Table 7.1: Simulated Almond Price, Plantings, Removals and Bearing Acreage: No Reserve Policy

Years	Farm price ($ 1985)	Plantings (acres)	Removals (acres)	Bearing acreage
1993	1.18	14,453	2,223	384,705
1994	0.97	11,738	78	393,857
1995	0.81	8,971	0	401,178
1996	0.59	6,407	3,734	472,074
1998	0.45	1,236	6,309	439,074
2000	0.13	0	11,528	426,115
2005	0.80	0	18,016	350,112
2010	1.76	6,558	370	308,627

consuming countries, and filbert prices and reasonable projected growth rates over time for these factors.[4] In this sense, the simulations should provide a reasonable indication of outcomes under the reserve scenarios posited. However, as simulations are carried further into the future, the results become increasingly speculative and are useful primarily in indicating the logical outcome from pursuing certain policies, not as outcomes that are expected to actually occur.

Table 7.1 reports results for selected years through 2010 of a no-reserve-policy simulation. Under the no-reserve simulation, each year's available supply is placed on the market and is free to move to various consuming countries or into carry-over for the next year. Almond industry records indicate that a high rate of plantings, on average about 10,000 acres per year, has occurred from 1988 through 1992. These plantings begin to bear in the simulation as the industry enters the mid 1990s. Table 7.1 thus forecasts a rather rapid increase in California bearing acreage through 1995. In turn, under a no-reserve scenario, the farm-gate price reported in *real* dollars per lb. kernel weight (deflated to 1985 prices) is projected to fall from $1.18 in 1993 to $0.81 in 1995.[5] The model forecasts further price declines through the remainder of the 1990s, which eventually begin to stimulate significant removals of acreage. As bearing acreage declines, price begins to recover after the year 2000, reaching a projected $1.76 in 2010. This price is sufficient to generate a new wave of plantings.

Note that the extremely low price projected in the year 2000 is not realistic. Diversions of product to secondary markets (almond butter, oils, feed) would occur even in the absence of a reserve to impose a price floor well above $0.13/lb.[6] Nonetheless the no-reserve simulation illustrates potential problems faced by the industry in the next several years from expansion of bearing acreage. The industry faces the prospect of dealing with very large crops which, in the absence of a well-conceived reserve policy, auger periods of low and declining prices.

The no-reserve simulation also indicates a tendency for the industry to move in a cyclical fashion; high rates of planting in the recent past and near future promise to stimulate large crops and low prices. In turn, these conditions induce removals in excess of 10,000 acres per year from 2000–2007 in the simulation. Bearing acreage eventually drops below current levels, price rises, and a new wave of plantings begins.

[4] All monetary variables were held constant in real terms. Population in consuming countries was projected to continue to grow in accord with each country's recent growth experience.

[5] The cumulative inflation factor between 1985 and 1993 was approximately 1.46.

[6] Harvest costs also place an effective floor on the farm price. At prices less than the harvest cost, estimated by University of California Extension to be about $0.19 per lb. kernel weight in 1992, growers will prefer to leave the crop on the tree.

This no-reserve outcome can be contrasted to results obtained by strategically designing a reserve policy to maximize a specific industry objective. We first consider design of a reserve policy to maximize industry profits in each year, given market demand conditions and the volume of harvest in California and elsewhere. The Almond Board may potentially increase profits in any given year by (*i*) regulating the total volume of almonds on the market and (*ii*) strategically allocating almonds among consuming markets. Specifically, the policy we study allows the industry to distinguish among three markets for pricing purposes: (*i*) North America (U.S. and Canada), (*ii*) Europe, and (*iii*) Japan. This type of reserve would enable California to discriminate between foreign and domestic sales and exploit the relatively inelastic foreign demands by restricting sales and raising price. Almonds not allocated to these three markets are disposed of in reserve.[7]

In Europe, the model subtracts Spanish supply from the total demand and maximizes California profits with respect to the residual demand in each period. Any Japan-Europe price difference cannot, however, exceed the per-unit costs of shipping between the two locations because of arbitrage possibilities from the low- to high-price region. Thus, model 1 restricts price discrimination between Europe and Japan to be no greater than the per-unit transactions costs (estimated to be $0.23/lb. in 1993) of shipping between the two regions. This arbitrage constraint is binding in the simulation because Japanese demand is significantly less elastic than European demand, calling for a considerably higher Japanese price in the absence of the constraint.

Table 7.2 presents results for selected years of this simulation. Several features of the table merit notice. To begin, the table suggests the magnitude of price differentials that emerge logically from discriminating against the inelastic-demand European and Japanese markets. The Europe-Japan price is roughly 2.5 times as large as the North America price. Caution is called for in interpreting this result. The price differences in the profit-maximizing reserve scenario are based upon linear versions of the demand functions described in Chapter 5. However, prices in the ranges depicted for Europe and Japan have not been observed to date, so we have no knowledge of whether indeed consumption would follow a linear relationship at these high prices.

Another striking result is the magnitude of the allocated reserve. The model projects that about one-third of the 1993 crop should have been held off the market.[8] Pursuit of a profit-maximizing reserve in each year is, not surprisingly, projected to stimulate plantings and diminish removals. Bearing acreage increases continually throughout the simulation period. Projected growth in production exceeds projected growth in demand in this simulation. Thus, attainment of the profit-maximizing reserve requires withholding progressively larger amounts of the crop in each year - nearly half the crop by the year 2010 according to the simulation.

7.3 Reserve Policy II: Optimal Reserve Strategies

Two key observations emerge from analysis of the short-run profit-maximizing reserve scenario:

[7]The Almond Marketing Order presently allows the industry to recommend to the Secretary of Agriculture the percentage of reserve almonds that may be sold to export destinations. Nonreserve almonds may be freely traded. The structure of the present order is thus to allow reserve almonds in certain cases to be "dumped" on the export market, an action likely to diminish industry revenues in the short run based upon our analysis. The Marketing Order may, therefore, require revision in order to implement the reserve policies discussed in this chapter. The impact of such a revision would be to raise welfare of both U.S. almond producers and consumers, the latter effect due to allowing discrimination *against* the export market rather than the domestic market.

[8]In reality no reserve was implemented for the 1993 crop.

Table 7.2: Simulated Almond Prices, Plantings, Removals and Bearing Acreage: Static Profit-Maximizing Reserve Policy

Years	N.A.	Eur	Japan	N.A.	Eur	Japan	Res	Plant	Remove	Bear
	Price ($/lb.)			Market Allocation (%)				Acreage (000)		
1993	1.25	3.09	3.31	39.2	22.8	4.8	33.2	13.9	3.6	365
1994	1.25	3.09	3.32	37.8	21.7	4.5	35.9	15.5	1.1	373
1995	1.25	3.09	3.32	40.5	23.1	4.8	31.5	20.5	0	381
1996	1.25	3.09	3.32	39.0	22.1	4.6	34.3	19.9	0	396
1998	1.25	3.10	3.33	38.7	21.6	4.5	35.2	18.6	0	437
2000	1.25	3.10	3.33	35.4	19.4	4.0	41.2	17.3	0	475
2005	1.26	3.11	3.34	33.5	17.5	3.6	45.3	14.1	0	558
2010	1.26	3.13	3.35	32.0	16.1	3.3	48.6	10.9	0	626

- California does have significant potential to raise average prices and profits through withholding almonds and discriminating against markets where demand is inelastic.

- Dogged pursuit of a static profit-maximization strategy will lead to greater bearing acreage through increased plantings and possibly decreased removals. Eventually, this supply response vitiates the effectiveness of reserve policy.

The industry can withhold increasing amounts of almonds, but it becomes very expensive to do so in that production costs are incurred for reserve almonds and the price to growers averaged across all production (sales + reserve) declines as production increases. A highly successful reserve policy is eventually its own undoing.

The issue is one of short-run vs. long-run profit maximization. An optimal reserve policy is one that takes into account that strategies designed to raise prices and profits will stimulate a countervailing planting response. We now discuss reserve strategies designed to maximize long-run industry profits, using as a point of departure the economic theory of cartel behavior. The model developed in this section assumes that the industry will seek to maximize the long-run discounted profit accruing jointly to the industry producers and handlers *at the time the reserve policy is set into place.* Even though a given policy may stimulate entry into the industry, the entrants' welfare would not be considered by the incumbents when setting the policy into place.

Fundamentals of Cartel Power

We argue that an industry regulating volumes under a marketing order is acting similarly to a cartel. Cartel behavior has been studied extensively, and Jacquemin and Slade (1989) have provided a thorough review of this literature. They list four prerequisites to achieving cartel power: (*i*) an agreement must be reached; (*ii*) because participants have incentive to cheat on any agreement that raises price, cheating must be detected; (*iii*) cheating, once detected, must be punished; and (*iv*) outside entry must be deterred.

These criteria help in understanding the role marketing orders play in facilitating cartel power. Once the marketing order is in place, agreement on a marketing policy requires only the concurrence of a majority of the Board's membership and, formally, the Secretary of Agriculture. Once a volume control policy is set in place, it has the force of law, thus encouraging compliance even among producers or handlers who disagree with the policy. Marketing orders include provisions for inspections to help detect cheating, and the legal force of the regulations, of course, facilitates punishment of cheating.[9]

Thus, the only prerequisite to cartel power not addressed through marketing orders is deterrence of outside entry. For example, successful almond marketing order volume regulations will stimulate expanded almond production from three sources: (*A*) current California producers under the order's control,[10] (*B*) new entrants under the order's control, and (*C*) producers outside the order's authority. Each of these types of entry affects a marketing order's profitability and optimal volume regulation strategy in different and as yet unexplained ways.

First, given that the marketing order's objective is to maximize the present value of the stream of profits of its existing membership—i.e., group (*A*) above, the costs of wasteful plantings and production undertaken by this group in response to the order's policies must be included as an explicit cost in the order's optimization calculus. Costs of expanding production incurred by new entrants and producers outside the order's authority, although likely to be wasteful from a societal perspective, would not be considered in an order's decision making. Second, although an order cannot prevent expanded production within its geographic coverage by current producers or new entrants, any new production is subject to regulation under the order. As such, the order can limit the amount of new production that reaches the market. In turn, this diversion requirement, if the order can commit credibly to future diversions, diminishes the profitability of new entry and thereby limits the expansion of production within the order's geographic domain. Conversely, production outside the order's auspices is not regulated under the order, meaning that outside producers can free ride on the order's market control activities. They can take advantage of higher, order-induced prices without submitting to volume regulation.

Dynamic Entry Deterrence

Translating this discussion into the context of the Almond Marketing Order, we find that raising short-term profits through reserve policy is expected to stimulate additional plantings from current California almond growers, new California entrants into almond production, and foreign (Spanish) growers. Spain in particular has the potential to benefit markedly from exercise of reserve policy by California producers for two reasons. First, short-run profit-maximizing price discrimination strategies call for California to restrict sales and raise price in Europe, where most Spanish almonds are exported. Second, Spanish growers will be free riders on any supply management by California, enabling them to attain higher prices for their entire exportable production.

A framework to incorporate entrant response into the exercise of cartel power is found in the literature on limit pricing. Limit pricing is essentially the notion that an optimal pricing strategy must consider not only the immediate profit impacts of the strategy but also any impacts on future entry and, hence, future profits. The concept dates to Bain (1968), who reasoned that a dominant firm or cartel would, if possible, set output and price so as to render entry just unprofitable for an entrant who was assumed to believe that the dominant firm's output rate would remain fixed despite entry.

[9]When cartel regulations are not legally enforceable, they must be self policing. Usually this implies a commitment by cartel members to respond to suspected cheating with aggressive competition (e.g., price cutting) so that cheaters' short-term gains are more than offset by long-term losses from upsetting the cartel agreement. See Friedman (1971), Green and Porter (1984), and Rotemberg and Saloner (1986) for analyses of self-enforcing cartel agreements.

[10]U.S. marketing orders, including the Almond Marketing Order, regulate volumes marketed at the level of the handler. They do not restrict the amount individual growers can produce. Thus, farmers are free to expand acreage and production in response to the higher price generated by the restriction of sales under the marketing order.

Gaskins (1971) provided the first explicitly dynamic treatment of the problem. He observed that a dynamically optimal pricing strategy for a dominant firm must balance short-term profits to be reaped from monopoly pricing with the prospect of reduced future profits due to entry from firms inspired by the high prices and profits being earned in the industry. Bain's prescription, which assumed entry deterrence, was too simplistic.

Gaskins showed that the problem of finding an optimal price path could be formulated and solved using optimal control theory. The dominant firm seeks to maximize the discounted present value of its profit stream, π, which is specified as follows:

$$\pi = \int_{+0}^{\infty} [P(t) - c]\, Q(P(t), t) e^{-rt} dt, \tag{7.1}$$

where $P(t)$ represents the product price, c denotes constant unit production costs, $Q(P(t), t)$ is residual demand facing the dominant firm, and r is the discount rate. The residual demand curve is found by subtracting entrant production $X(t)$ from the market demand $f(P(t), t)$:

$$Q(P(t), t) = f(P(t), t) - X(t). \tag{7.2}$$

The rate of entry of rival producers in Gaskin's model, $\dot{X}(t)$, is determined as a simple linear function of the difference between the dominant firm's price and a limit price, $\bar{P}$:

$$\dot{X}(t) = k\left[P(t) - \bar{P}\right], \; X(0) = X_0, \; \bar{P} \geq c. \tag{7.3}$$

Subsequent authors have modified and generalized the basic Gaskins model. Kamien and Schwartz (1971) modeled entry as a stochastic process so that the likelihood of entry is an increasing function of the market price. They later (1975) extended the analysis to consider limit pricing by Cournot oligopolists facing uncertain entry. Bourguignon and Sethi (1981) further generalized the approach to allow heterogeneity among entrants and to incorporate advertising as a potential tool of entry deterrence.

The primary criticism levelled against Gaskins' model and its subsequent refinements is that entry is not modeled as an equilibrium process. Entrants do not behave strategically nor respond rationally to the dominant firm's strategy. Rather, entry unfolds according to a rule such as that stated in (7.3). The optimal control model developed for this study is adapted from Gaskins' basic framework and, thus, can also be criticized on these grounds. Important factors, however, mitigate the force of these criticisms. First, supply response for both California and Spanish farmers is based on the econometric models described in Chapters 3 and 4 and not on ad hoc algebraic formulations such as (7.3). Second, the entrants at issue here are growers or potential growers of almonds in California and Spain. Most almond production is by relatively small farmers, and it is quite realistic that their supply decisions are based on simple rules concerning present and/or recent past prices rather than on conditional forecasts of future prices derived from economic models.

Gilbert (1989), writing in the *Handbook of Industrial Organization*, offers a similar assessment of the Gaskins model:

> Despite its theoretical limitations, the Gaskins model of dynamic limit pricing is an appealing description of pricing behavior for industries that are characterized by dominant firms. The exogenous specification of the entry flow is not theoretically justified, but it may capture an important element of dynamic competition...The exogenous specification of the entry flow is not inconsistent with an environment in which potential entrants have imperfect [in]formation about the existence of entry opportunities and where searching out entry opportunities is costly and time-consuming.

The Dynamic Optimization Model

The optimal control model developed for this study seeks to maximize the discounted profits to current members of the California almond industry at the time a strategy is set into place. This group is denoted by the subscript '1'. New California entrants into almond production are denoted by '$\sim$1'. Non-California almond production is denoted with an 'F' subscript. To simplify the analytic expression of the model, we do not distinguish demands among countries. Rather, only aggregate inverse demand $P(Q(t), t)$, where $Q(t) = Q_1(t) + Q_{\sim 1}(t) + Q_F(t)$, is considered and, therefore, price discrimination is not an issue. The empirical programming model relaxes this constraint and allows discrimination between domestic and export markets. We assume that processing/handling takes place under constant returns to scale, so that the model need not consider rents to handlers and $P(Q(t), t)$ can be interpreted as farmgate demand for almonds (i.e., final product demand less per-unit handling costs). $C_1(Q_1(t), t)$ denotes current California growers' variable cost function for producing almonds, $f_1(PL_1(t), t)$ denotes this group's investment cost function for planting new almond acreage, PL_1, and B_i, $i = (1, \sim 1, F)$, denotes bearing acreage for producer group i. For convenience removals are assumed costless on net due to the salvage value of the wood. The Almond Board's control variable is $\gamma(t) \geq 0$, the percentage of the California almond harvest released to the market. The objective functional is

$$\begin{aligned}\pi \;=\; & \int_0^{\infty} P\left[\gamma(t)\left(Q_1(t) + Q_{\sim 1}\right) + Q_F(t)\right]\left[Q_1(t)\gamma(t)\right] e^{-rt}\, dt \\ & - \int_1^{\infty} C_1\left(Q_1(t)\right) e^{-rt}\, dt - \int_1^{\infty} f_1\left(PL_1(t)\right) e^{-rt}\, dt \qquad (7.4)\end{aligned}$$

Constraints on (7.4) are set forth below. The key constraint is (7.5) which specifies output response by each of the three producer groups:

$$\dot{Q}_i(t) = \dot{B}_i(t)\bar{Y}_i(t), \;\; i = 1, \sim 1, F, \qquad (7.5)$$

where $\bar{Y}_i(t)$ denotes exogenous yield. The equations in (7.6) represent initial conditions:

$$\begin{aligned} Q_1(0) &= Q_1^0, \\ Q_{\sim 1}(0) &= Q_{\sim 1}^0, \\ Q_F(0) &= Q_F^0. \end{aligned} \qquad (7.6)$$

Equations (7.7) provide the linkage between acreage response, $B_i(t)$ in (7.5), and growers' planting, PL_i, and removal, R_i, decisions:

$$\dot{B}_i(t) = PL_i(t-4) - R_i(t-1), \;\; i = 1, \sim 1, F. \qquad (7.7)$$

Formulation of the analytical model is completed by replacing PL_i and R_i in (7.7) with functional specifications for the plantings and removals decisions. These are discussed in chapters 3 and 4 for California and Spain, respectively, for the almond industry application. A fundamental complication is encountered, however, in distinguishing the supply response within the marketing order area that is due to expansions by current producers from that of new entrants into almond production. As noted in the preceding discussion, such a delineation is crucial in establishing the optimal trajectory for reserve policy, given the objective of maximizing profits of *current* members of the almond industry.[11]

Conceptually it is possible to specify different supply response functions for the two groups of producers. However, estimated supply response functions such

[11] Of course, if the objective were, instead, to maximize the profits of both current and prospective California growers, it would be unnecessary to distinguish their supply responses. The same would also be true if the objective were broadened to include the interests of U.S. consumers.

as those contained in Chapters 3 and 4 will ordinarily capture the total supply response for both entrants and current producers within a geographic area; the available data will not permit the responses by entrants and incumbents to be identified separately. We addressed this problem by developing a procedure to decompose a given aggregate supply response into proportions due to entrants vs. current producers. The procedure is described in detail in Appendix B. Briefly, it arrays growers or potential growers along a continuum $i \in [0,1]$, and assumes that each grower or potential grower has a fixed value A_0 of acreage. Land is not homogeneous, and yield per acre for each grower is a decreasing function of the number of acres, B_i, planted into the crop: $Y_i = f_i(B_i|t)$, $f_i' < 0$, where t denotes possible dependence of yield upon age structure of the planting. In modelling f_i we assume that $f_i(\cdot) = \theta_i f(\cdot)$ for all i, where $\theta_i \in [k,1]$ is a shift parameter and $0 < k < 1$, so that $\theta_j > \theta_i$ implies that j's acreage is absolutely more suited to growing the product than i's acreage and/or that j is an absolutely more productive manager of production than i. It is assumed that growers in $[0,1]$ are distributed uniformly on $[k,1]$ with relative frequency thus equal to $1/(1-k)$.

It is then possible to identify a value of θ, say, θ^*, where it is assumed that $\theta^* \in (0,1)$, such that growers whose efficiency levels are denoted by θ^* just earn zero discounted expected profits given the projected competitive (no reserve) net investment stream, R^c, from almond production. Growers with efficiency indices in $[\theta^*,1]$ comprise the group of current producers and produce quantities Q_i, and those with indices in $[k,\theta^*)$ comprise the group of potential entrants. Total supply under the no-reserve scenario is simply:

$$Q_1(R^c) = \frac{1}{1-k}\int_{\theta^*}^{1} Q_i \, d\theta.$$

Supply response to a discounted revenue change can be decomposed into that of new entrants and expansion by incumbents by using Liebnitz's rule, as shown in equations (B.8) and (B.8′) in Appendix B. An important point illustrated by these equations is that when fixed entry costs are high, entrants join production discontinuously, i.e., at a "large" output level, whereas incumbents respond only incrementally to higher prices.[12] Thus, even though entrants may be small in number compared with incumbents, the magnitude of their supply response may be relatively large.

7.4 The Empirical Programming Model

An analytical solution to the optimal control model set forth in equations (7.4)–(7.7) is not possible because the model involves delayed response and has two state variables. Delayed response is a consequence of the gestation period between planting and initial harvest inherent to perennial crops. The control variable, $\gamma(t)$, affects current planting decisions which affect production after a four period lag. Similarly, removals decisions affect production with a one-period lag.[13] The two state variables are the supply responses by California and foreign almond producers.[14]

As an alternative to analytical solution of the model, it was calibrated and solved as a finite-horizon nonlinear optimization problem using the GAUSS computer program. The various solutions presented below were checked and found to be robust

[12] This result is at odds with conventional wisdom which says that high fixed and sunk entry costs insulate incumbents from entry.

[13] See Kamien and Schwartz (1991) for a discussion of delayed response in the context of control models.

[14] The procedure described in the appendix to this chapter reduces the state variables from three to two by enabling incumbent producers and entrants within the marketing-order area to be treated jointly.

to alternative starting values for the optimization procedure. The steps to developing the model are described below, followed by the analysis of alternative marketing order strategies.

Construction of the Programming Model

The empirical model was designed to solve for the trajectory of marketing order strategies that maximizes profits for existing (as of 1993) California almond producers over a discounted 50-year horizon. In presenting a 50-year trajectory of marketing order strategies, the programming model provides a numerical solution to the *open-loop* version of the analytical control problem. In other words, it assumes the industry can commit at the outset of the horizon to implement the entire 50-year trajectory of reserve strategies. The model allows the industry to designate almonds for sale into (*i*) the domestic market (Canada and the U.S.), (*ii*) the export market, and (*iii*) disposal. The export market was not broken down between Europe and Japan to facilitate solution of the model.[15]

The structure of the empirical optimization model is depicted in Figure 7.1. Almond demands in the domestic and export markets were based on linearized and aggregated versions of the demand functions described in Chapter 5, using the same procedures as discussed in Chapter 6. Demand was calibrated to 1993 levels, and allowed to grow at annual rates between 0.5 and 1.5 percent. Spanish exports were subtracted from total export demand to arrive at residual demand facing California in the export market. A modest value of $0.20 per lb. was assigned to reserve almonds. Given the long-run character of the model, year-to-year fluctuations in inventories were not modeled; inventories were treated as a constant over time.

California almond plantings were represented by the "traditional" plantings model contained in equation (3.15).[16] The procedure described in Appendix B was used to decompose planting response between incumbents and entrants.[17] Removals of California almonds were treated exogenously: Each year 2.5 percent of the total California bearing acreage was removed.[18] Spanish supply response was represented by the net plantings model (plantings less removals) summarized in equation (4.5). Yields in both California and Spain were expressed as constants. For current California growers yields per acre were set at 2000 lbs. in shell and 2200 lbs. in shell for California entrants, reflecting modestly higher long-run yields for modern tree stock. Spanish yields were set at 350 lbs. per acre in shell.

All monetary variables in the programming model were specified in real values (1985 dollars), and future returns were discounted at a 2.0 percent real rate. Orchard establishment and almond production costs were adapted from budgets compiled by the University of California Cooperative Extension. These costs in real terms were treated as constants over the 50-year horizon. Income taxes were set at a combined Federal and State rate of 34 percent.

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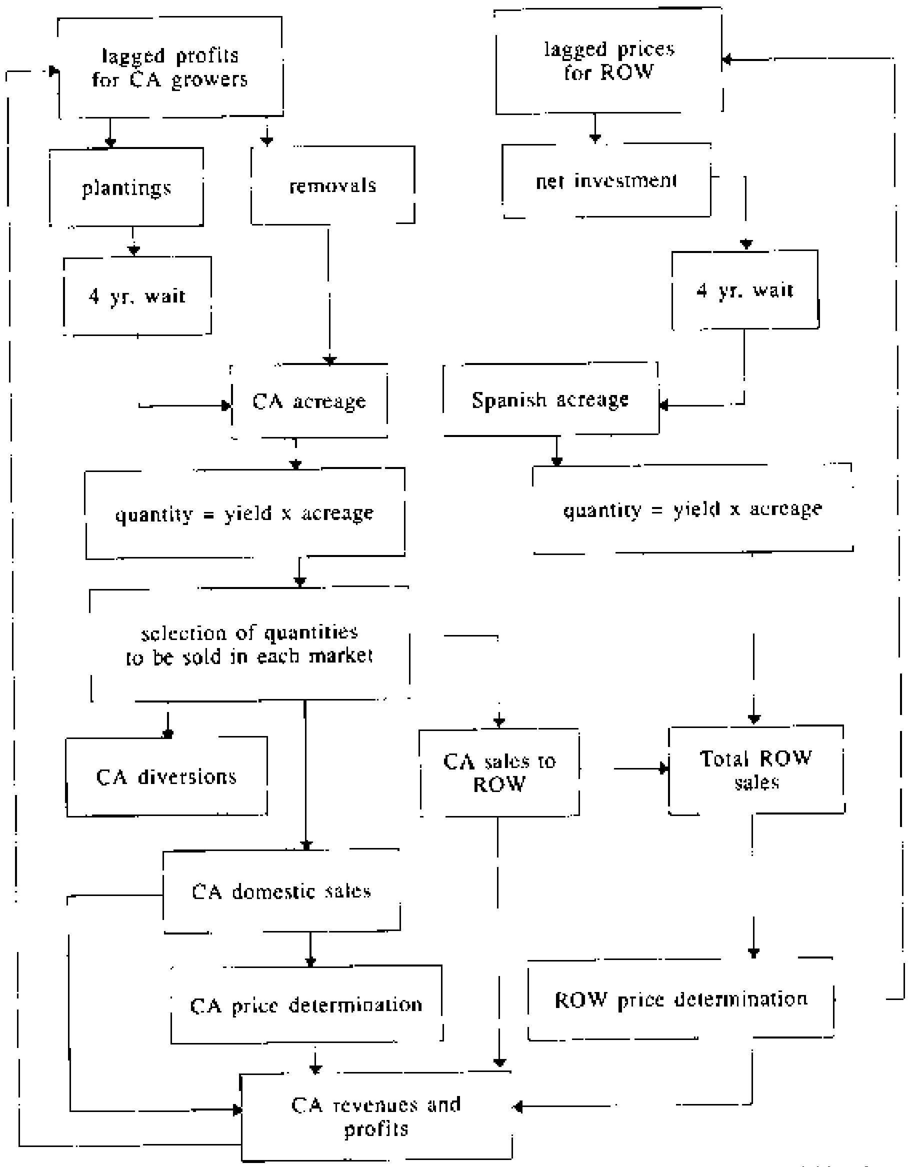
[15]The model, thus, involves choice of 150 parameters (3 market outlets times 50 years), although only 100 are free due to the constraint that the allocation proportions must sum to 1.0.

[16]The expected net present value model was not used in this analysis because of the burdensome programming and computation problems it would have entailed. Essentially for each year of the 50-year horizon, a new net present value calculation would be required, incorporating updated price information.

[17]Using the notation from the appendix, the key parameter values to calculate the entrant and incumbent shares of investment are $R = 2450$, $K = 1800$, $E = 1960$, all measured in dollars per acre. The slope δ of the yield curve was set at 0.002. These figures result in estimated shares of expanded acreage of 29.37 percent and 70.63 percent for entrant and incumbent growers, respectively.

[18]This specification is consistent with the long-run character of the programming model. Under an optimal reserve strategy, almonds would not be removed prematurely due to unprofitability. Rather, age would be the primary factor driving removals. The 2.5 percent annual removal rate is consistent with a steady-state 40-year life for an almond orchard.



Note: Entrant and existing grower acreage and production are tracked separately within the model but do not affect the working of the model since new entrants immediately fall under the auspices of the ABC.

Figure 7.1: The Reserve-Policy Optimization Model

Table 7.3: Optimal 50-Year Reserve Strategies for Alternative Demand Growth Rates

Year	0.5% Demand Growth			1.0% Demand Growth			1.5% Demand Growth		
	Dom. P ($/lb.)	Exp. P ($/lb.)	Res. %	Dom. P ($/lb.)	Exp. P ($/lb.)	Res. %	Dom. P ($/lb.)	Exp. P ($/lb.)	Res. %
1993	1.60	1.31	11	1.44	1.18	1	1.47	1.17	1
1994	1.73	0.82	8	1.58	0.86	0	1.64	0.82	1
1995	1.70	1.08	10	1.71	0.68	1	1.65	0.85	0
1996	1.91	0.20	2	1.69	1.03	4	1.61	1.19	2
1998	1.91	0.00	0	1.80	0.56	1	1.83	0.63	0
2000	1.44	1.30	9	1.59	0.72	1	1.65	0.77	1
2005	1.37	1.11	11	1.37	1.13	4	1.35	1.33	6
2010	1.30	1.24	13	1.17	1.53	10	1.21	1.63	17
2015	1.14	1.44	20	1.14	1.71	24	1.27	1.87	32
2020	1.07	1.64	28	1.23	1.84	37	1.30	1.97	41
2025	1.09	1.80	36	1.28	1.98	45	1.33	2.00	47
2030	1.11	1.93	42	1.30	2.10	50	1.32	2.15	51
2035	1.15	2.12	45	1.30	2.27	52	1.31	2.37	53
2042	1.15	2.21	46	1.31	2.35	53	1.32	2.42	53

Results

Table 7.3 summarizes results for the baseline optimization model for alternative demand growth rates of 0.5, 1.0, and 1.5 percent. The baseline model allows the Almond Board to allocate almonds between the domestic and export markets and to commit almonds to disposal outlets. Table 7.3, when compared with Table 7.2, illustrates the marked changes in reserve strategy that emerge from considering the implications of reserve policy for future supply response. Under either of the three demand growth scenarios, the optimal long-term reserve strategy calls for California to refrain from exploiting the inelastic export market in the early periods of the 50 year horizon. With 0.5 percent annual demand growth, discrimination against the export market does not begin until period 20 (year 2012). It occurs slightly sooner in the models with higher rates of demand growth year 15 in the 1.0 percent growth model and year 14 in the 1.5 percent growth model. Even after price discrimination against the export market begins, the magnitude of discrimination remains modest through the middle years of the horizon, and only approximates the static profit-maximizing magnitude in the last periods of the horizon.

Failing to discriminate against the export market and, in fact, dumping product abroad diminishes incentives for expansion of Spanish almond production. Recall that Spain, as a producer outside the marketing order's control and a seller that emphasizes the European export market, benefits when California discriminates against the export market.

A similar story holds for the magnitude of the reserve itself. Under each of the three demand growth scenarios, the percentage of crop committed to reserve is small in the initial years and gradually increases over time. At the end of the horizon about half the crop is committed to reserve under each demand growth scenario. By choosing not to set the static profit-maximizing amount of reserve, the marketing order diminishes incentives for expanded production from both California and Spain, thereby increasing profits in future periods. The increase over time in reserves occurs for two reasons. First, as almond production becomes increasingly profitable, supplies grow faster than demand, necessitating commitments to reserve of ever greater volumes. Second, as the horizon unfolds, future outcomes become less important, enabling the industry to extract higher profits through aggressive reserve

Table 7.4: Optimal Reserve Policy Analysis: Base Model with One Percent Demand Growth

	Percentage Allocation			Net Investment Response (acres)			CA Profits
Year	Domestic	Export	Reserve	CA Incumbents	CA Entrants	Spain	($/acre)
1993	48	51	1	-		-14.321	1,265
1994	42	58	0	11.338	8.937	-13.486	986
1995	37	62	1	22.493	13.563	-11.801	782
1996	38	58	4	-337	4.043	-13.484	1,161
1998	33	66	1	-1.959	3.204	-13.654	722
2000	40	60	1	17.088	13.573	-12.627	815
2005	45	50	4	3.486	8,344	-12,611	1,077
2010	48	41	10	12.728	17,111	-5,274	1,081
2015	42	32	24	8,232	18,839	1,167	905
2020	35	29	37	5,271	20,905	5,307	789
2025	30	25	45	2,640	22,459	10,841	702
2030	28	22	50	147	23,313	16,982	633
2035	27	20	52	-942	10,466	26,654	632
2042	28	20	53	-1,757	9,423	39,934	640

policy despite the effect such profits have on future entry. The magnitude of reserve is highest in the early years of the horizon under the 0.5 percent demand growth simulation. Due to slow demand growth, the profitability of almond production is less than under the higher-growth scenarios, enabling the industry to pursue a more aggressive reserve policy in the early periods without stimulating too much entry.

Table 7.4 provides a more detailed look at the optimization model results for the baseline reserve policy model with 1.0 percent demand growth. The first three columns indicate the percentages of production committed to domestic, export, and reserve outlets. The next three columns indicate the magnitude of annual net investments (plantings less removals) in almond acreage from California incumbents, California entrants, and Spanish producers. In interpreting the table, recall that California incumbents refer to the current group of almond producers as of 1993, and that removals of California acreage are treated exogenously, so removals for the entrant group do not begin until year 40. The Spanish investment model from Chapter 4 predicted net investments directly. The final column of the table indicates variable profits per acre net of taxes to California incumbents.

The percentage allocations to the alternative market outlets reinforce the story of increasing discrimination against the export market told by the price paths contained in Table 7.3. The investment response columns indicate the degree of success of the optimal reserve policy in affecting entry. On net Spain *disinvests* in almond orchards through the year 2013 under the optimal policy. In total over 215,000 net acres of Spanish almond orchards (15 percent of total acreage) are removed under the optimal policy from 1993–2013. However, as profitability of Spanish almond production increases in the later years of the horizon due to California discrimination against the export market, Spanish almond acreage begins to expand. Spain's bearing acreage at the end of the horizon totals 1,578,000 acres, a 9.7 percent increase from the 1993 total.

Conversely, the optimal reserve policy is much less effective at mitigating entry in California. Both incumbents and entrants invest heavily in almond orchards throughout the 50-year horizon in response to the profits earned by pursuing the optimal reserve strategy.[19] Entry by California producers is less damaging to the

[19]The large expansion in California acreage projected by the reserve strategy simulation is consistent with the conceptual discussion of supply response in the almond industry contained in

marketing order's effectiveness because the expanded production can be controlled through the reserve policy. Roughly 50 percent of the crop is devoted to reserve in the later years of the horizon. Production in Spain, which is not subject to the order's control, has the potential to be very damaging, so the optimal reserve policy calls for depressing the profitability of Spanish almond production in the early periods of the 50-year horizon by dumping almonds in Spain's primary export markets.

Real variable profits per acre to the California incumbent almond growers tend to be highest during the middle years of the horizon, reflecting the increasing stringent reserve policy controls invoked during this time and also the modest expansion in acreage that has occurred to that point in the horizon. Profits fall in the later periods because expanded acreage and increased harvests force increasing amounts of production into reserve.

Analysis of Alternative Reserve Strategies

In addition to the baseline reserve strategy, which enabled the Almond Board to allocate almonds among domestic, export, and reserve market outlets, we also considered two alternative, more restrictive marketing order strategies. One strategy precluded price discrimination between the domestic and export markets but continued to allow almonds to be diverted to secondary markets. This type of strategy is consistent with policies that might emerge under the Almond Marketing Order as it is presently configured. In particular, the present order lacks provisions for restricting the flow of almonds into the export market. The second restrictive strategy scenario allows the Almond Board to price discriminate between the domestic and export markets but does not allow the Board to divert almonds to secondary uses. This policy might be considered as a politically feasible alternative to the more flexible baseline strategy. Specifically, many almond growers are disinclined to see their production disposed of as animal feed or otherwise diverted into seemingly unproductive uses. Thus, a reserve strategy that did not involve this type of disposal but, rather, limited intervention to strategic allocation of product among markets for human consumption might be preferred by growers.

Table 7.5 summarizes the optimal reserve strategy and ensuing market results for the no-price-discrimination policy. Without the capacity to price discriminate, the optimal strategy for the marketing order involves consigning considerably greater quantities of almonds to secondary markets during the early years of the horizon. In contrast to the base model where one percent or less of the harvest was committed to reserve through the year 2000, 18–19 percent is committed annually to reserve under a strategy of no price discrimination. These large reserves produce favorable prices and a high rate of plantings in California through the 1990s. Spain, however, due to the lower productivity of its almond orchards, actually undertakes modest disinvestment during the 1990s. Increased California production begins to drive the real price down after 2000. The optimal policy, however, calls for the reserve to remain relatively constant in the 20 percent range, with the consequence of causing significant disinvestment in Spain in the range of 10,000 acres annually and a significantly reduced rate of investment in California. With demand growth continuing at 1.0 percent, the reduced rate of plantings eventually stimulates an upturn in real prices in the latter years of the horizon. California per acre profits under this strategy are highest in the first years of the horizon and then decrease dramatically until beginning a modest upturn after 2020.

Table 7.6 illustrates what an optimal marketing order policy might look like if the industry chooses to target reserve policy activities to strategic allocations of product between domestic and export markets and not allocate product for disposal.

Chapter 3, which indicated that supply response might be very elastic in the long run.

Table 7.5: Optimal Reserve Policy Analysis: No Price Discrimination

		Percentage Allocation			Net Investment Response (acres)			CA Profits
Year	Price	Domestic	Export	Reserve	CA Incumbents	CA Entrants	Spain	($/acre)
1993	1.65	38	43	19	..		-11,321	1,388
1994	1.66	38	44	18	14,753	10,358	-12,021	1,355
1995	1.68	33	44	18	34,322	18,483	419	1,301
1996	1.71	37	45	18	18,814	12,006	1,004	1,393
1998	1.70	37	45	18	23,638	13,848	3,046	1,363
2000	1.50	39	41	19	16,688	14,058	-295	1,106
2005	1.17	42	38	21	6,275	13,123	-9,041	699
2010	1.00	42	37	21	1,149	12,669	-11,294	503
2015	0.93	42	37	21	-1,294	12,443	-11,572	422
2020	0.91	42	37	21	-3,565	12,301	-11,281	399
2025	0.91	42	37	21	-4,799	12,136	-10,788	408
2030	0.94	41	38	21	-5,027	11,995	-10,195	439
2035	1.06	40	40	20	-4,290	3,107	-9,137	506
2042	1.20	39	42	19	-4,794	6,765	-7,116	788

As with the baseline reserve strategy, this restrictive reserve strategy also calls for California to discriminate against the domestic market throughout much of the 50-year horizon, despite the static profit-maximizing prescription to the contrary. Except for 1993, the optimal export price is less than the domestic price each year until period 32 of the horizon. Not surprisingly, this policy is very successful at encouraging disinvestment in Spain, which removes almonds on net throughout most of the 50-year horizon. Under the reserve simulation, bearing acreage in Spain falls from 1.44 million acres at the outset of the horizon to 1.01 million acres at its conclusion, a decrease of 29.9 percent.

Under this strategy, investment by California incumbents is initially high but then declines and approaches a steady state after 2010 where plantings essentially are matched by removals. Per acre profits to California incumbents are rather stable throughout the horizon under this policy.

7.5 Summary of Reserve Policy Alternatives

This chapter has considered evolution of the California almond industry into the 21st century under alternative scenarios for reserve policy. Section 7.2 analyzed industry behavior (*i*) in the absence of reserve policy, and (*ii*) in the presence of a reserve designed to maximize profits to the industry in each year. Sections 7.3 and 7.4 analyzed the dynamic elements of reserve policy and discussed design and implementation of reserve policies that were optimal over a multiyear horizon. Table 7.7 provides a summary comparison of bearing acreages and discounted cumulative profits under the alternative strategies for the scenario of 1.0 percent demand growth. To obtain consistent results, the no-reserve and static profit-maximizing reserve models discussed in section 7.2 were resimulated within the framework of the empirical optimization model described in section 7.4.

Table 7.6: Optimal Reserve Policy Analysis: No Price Diversion to Secondary Markets

Year	Price: Dom	Price: Exp.	Allocation: Dom	Allocation: Exp.	Net Investment: CA Incumbent	Net Investment: CA Entrant	Net Investment: Spain	CA Profits
	$/lb		%		acres			($/acre)
1993	1.34	1.37	52	48	-		-14,321	1,366
1994	1.52	1.01	45	55	14,133	10,100	-13,005	1,096
1995	1.61	0.85	41	59	27,325	15,572	-9,896	944
1996	1.74	0.67	36	64	4,958	6,244	-12,571	839
1998	1.79	0.47	33	67	-9,312	147	-14,126	655
2000	1.46	0.75	43	57	8,676	9,709	-13,662	838
2005	1.52	0.67	41	59	4,112	8,454	-12,751	790
2010	1.39	0.71	43	57	2,391	9,456	-12,143	780
2015	1.25	0.82	47	53	2,338	11,380	-11,237	795
2020	1.10	0.87	49	51	419	11,811	-10,504	744
2025	0.92	1.07	53	47	-300	13,189	-9,128	758
2030	0.77	1.20	56	44	-2,041	13,052	-7,882	720
2035	0.65	1.71	61	39	40	8,538	-133	875
2042	0.63	1.82	61	39	573	9,865	6,052	919

Table 7.7: Comparison of Alternative Reserve Strategies

Reserve Strategy	CA incumbents	CA entrants	Spain	Discounted Profits to CA Incumbents ($ millions)
	Year 50 Bearing Acreage			
1. No Reserve	436,449	371,886	978,385	10,513
2. Static Profit-max reserve	562,839	627,642	2,546,080	12,363
3. Baseline reserve	603,268	625,451	1,577,833	13,002
4. Disposal: no price discrim.	490,019	460,972	1,052,413	10,988
5. Price discrim.: no disposal	463,566	405,793	1,005,342	11,237

The present value of the gain from pursuing the fully optimal baseline reserve strategy (row 3) as opposed to the simpler static profit-maximizing strategy (row 2) is $639 million, or about 5.2 percent. The discounted gain over no reserve policy (row 1) is much more substantial: $2,439 million or 23.7 percent. The results from the models of the restrictive reserve policy illustrate the amount of profit foregone from failing to utilize all of the tools at the industry's disposal. Most of the foregone profit ($2,014 million) results from failure to discriminate between the domestic and export markets. The discounted profit from this reserve strategy (row 4) is only 4.5 percent greater than the projected profits from employing no reserve at all. Failure to dispose of almonds in secondary markets (row 5) is projected to reduce discounted profits by $1,765 million or 13.6 percent, compared to the optimal reserve strategy.

The various models also illustrate how investments in almond acreage may be influenced by alternative types of reserve strategies. The static profit-maximizing reserve, which takes no account of entry responses, results in a projected explosion of almond acreage in Spain to over 2.5 million acres, compared with the present 1.4 million acres. This type of projection must be interpreted with circumspection because the projected acreage is well beyond the range of the data used to estimate the Spanish supply response model. Nonetheless, the result is indicative of the potential consequences of failing to consider the dynamics of reserve policy.

The no-reserve outcome, because it yields the lowest profit, is most successful at controlling expansion of almond acreage. In fact, acreage in Spain is projected to contract over the 50-year horizon under no reserve or under the restrictive reserve policies. The largest expansion in California acreage occurs as expected under the optimal baseline strategy due to its success in funneling almond profits into the hands of California producers and away from Spanish producers.

7.6 Conclusion

This chapter has presented an alternative approach to studying behavior of industries operating under the auspices of a marketing order with volume regulations. Based on economic theories of cartel behavior and dynamic limit pricing, this chapter has studied marketing order behavior within an optimization framework. On the other hand, the traditional approach, based on the work of French and King and various associates, has used an econometric approach to predict marketing order decisions in terms of exogenous variables believed to influence those decisions; no explicit optimization is involved.

Each approach would appear to have advantages and disadvantages. The econometric approach is useful as a *behavioral* model in that it attempts to predict future industry behavior through a function estimated from data reflecting past industry actions. The optimization approach of this chapter also may be used for behavioral analyses. The assumption of optimizing behavior that underpins it is, for example, fundamentally similar to optimization assumptions that are the foundation of the neoclassical models of the firm. However, there is no solid evidence to suggest that marketing order decision makers do optimize in the ways postulated here, i.e., it is unclear that any of the general or constrained optimization models described in this chapter reflect accurately the actual decisions made by the Almond Board. Arbitrage arguments used to demonstrate that firms must optimize to survive do not apply directly to the context of a marketing order.[20]

The optimization framework is more flexible for conducting policy analyses than is the econometric approach. This latter approach has been primarily used to simulate industry behavior in the presence vs. the absence of the marketing order, with absence simulated by essentially "setting to zero" the marketing order's control variable. This chapter has shown how the optimization framework, through the device of introducing constraints into the optimization problem, can simulate behavior under a variety of industry strategies and policies. It is, thus, useful as a normative tool for industry decision makers to evaluate the consequences of alternative strategies they might pursue. Even if industry decision makers have not fully or effectively utilized the tools at their disposal, the optimization framework illustrates the outcomes that can be achieved. In this sense, it is also useful to public policy makers interested in the potential effects of marketing order volume regulations.

[20]Competitive firms that fail to maximize profits will be driven from the industry in the long run. Imperfectly competitive firms that fail to optimize are vulnerable to reorganization through acquisitions or hostile takeovers. It might be argued that marketing order decision makers that failed to optimize would be voted out of office by members of the industry, but this arbitrage link is much more tenuous than the market processes that cause firms to optimize.

8. SUMMARY AND CONCLUSIONS

This report has contained the results of an extensive study of the California almond industry and related markets. Chapters 2–5 documented a number of key findings concerning demand and supply factors that impact upon the industry. Some of the major findings are summarized below in checklist form:

- Almond yields in California are highly volatile, but yields can be predicted with good accuracy as a function of past yields (the alternate bearing effect), February rainfall, and the age distribution of almond trees.

- Acreage response to industry policies which affect prices and profits has the potential eventually to offset those policies fully. However, complete supply offset in the almond industry only takes place in the long run. Short- to medium-run acreage adjustments through plantings and removals are affected by growers' perceptions of future expected revenues and variable costs. Changes in tax policy also have had some impact on investment in the California almond industry.

- The major competitor to the California almond industry is the Spanish almond industry. Spanish almonds are a close substitute for California almonds in several key European markets. Thus, short-run and secular changes in Spanish almond production have important effects on the California industry.

- Spanish almond acreage has been gradually on the rise since 1970, but yield and production are highly volatile. However, we had good success in estimating Spanish yields as a function of past yields, age of trees, and rainfall during key months. In addition, an acreage response model for Spain indicated that the Spanish industry responds to incentives in the same way as does the California industry.

- Inelastic demand for California almonds in export markets suggests that the industry can raise prices and profits in the short run by restricting the flow of almonds to these markets. Pursuit of this policy will lead to gradual erosion of the California almond industry's share of the world market, as competitors respond to higher prices with increased rates of almond plantings.

- Price elasticity of demand differences among major consuming countries can be exploited by restricting flows of almonds to countries with less elastic demands. In particular, the demand for almonds in the United States appears to be more elastic than almond demand in major importing countries. However, where resale of almonds among countries is easy (e.g., within Europe), such price discrimination strategies will be unsuccessful.

- Promotional campaigns for California almonds in general need not focus on positioning almonds relative to other nut products, because other nuts do not appear to be good substitutes for almonds. Filberts in some European markets are an important exception to this rule.

Chapters 6 and 7 of the report discussed integration of the supply-demand analysis of Chapters 2–5 to develop both simulation and optimization models of the almond industry. Use of the simulation model to project the consequences from adopting a reserve strategy designed to maximize annual profits to the California almond industry demonstrated that such a policy may become disadvantageous over the long run because of California and Spanish supply responses stimulated by high profits from almond production. The optimization model treated the structure of supply and demand in the industry as given and derived reserve trajectories that were optimal over a discounted 50-year horizon.

The optimal strategy involved considerable moderation on the California industry's part. In particular, price discrimination against the export market, prescribed as part of the static profit-maximizing strategy, did not emerge under the optimal strategy until year 15 of the 50-year horizon. Rather, the optimal reserve strategy called for California to selectively dump product abroad to diminish incentives for expansion of Spanish supply. Only in latter periods of the horizon did discrimination under the optimal strategy approximate that of the static profit maximum. The industry was estimated to gain about five percent, $639 million, from pursuing the optimal strategy vs. the static profit maximization rule. The incremental profit over no reserve strategy at all was 23.7 percent or 2.44 billion dollars, demonstrating that the ability to implement reserve strategies is a powerful tool at the California industry's disposal.

The optimization framework was also used to simulate the trajectory of market outcomes under various restrictive reserve policy strategies. The results suggested that failure to price discriminate between domestic and export markets could cost the industry about two billion dollars of discounted profit over the 50-year horizon. A strategy of price discrimination but no disposal of almonds in reserve markets resulted in an estimated loss of $1.77 billion relative to the optimal strategy.

The reserve policy analyses conducted in this study were open loop in the sense that they assume the industry can commit in advance to a trajectory of strategies and maintain it over the entire planning horizon. Current members of the Almond Board, however, have little scope to tie the hands of their successors. A useful direction for future work, thus, will be to consider various closed loop strategies whereby commitments to a reserve strategy can only be made for a finite interval, e.g., the tenure of a group of Board members. Each successive Board is free to design its own reserve strategies under these models. Work by Karp (1987) in the context of international tariffs suggests the likely consequence of the industry's inability to commit itself; as the interval of commitment approaches only a single-period commitment, the trajectory of closed loop strategies collapses to the static profit-maximizing trajectory.

A. CO-INTEGRATION AND UNIT-ROOT TESTS OF THE LAW OF ONE PRICE

This appendix describes the unit-root tests used to examine the hypothesis that the world's almond markets are linked sufficiently closely to permit the replacement of one price with a linear transformation of another price in a simulation model. We test, in particular, whether a Law of One Price (LOP) holds in the almond market.

Co-integration techniques can be used to identify interdependence between time series which exhibit non-stationary behavior. If two series x_t and y_t are generated by processes that are integrated of order 1 (written $I(1)$), that is

$$x_t = x_{t-1} + \epsilon_{xt}$$

and

$$y_t = y_{t-1} + \epsilon_{yt}$$

where the ϵ_{jt} are white noise, then simple regressions of x_t on y_t, or of y_t on x_t, will frequently give spurious evidence of a relationship between x_t and y_t, even when the two series are in fact independent (Granger and Newbold 1974). The independence of the two series can, however, be detected in the residuals from the regressions between the two series: these residuals will be an $I(1)$ process. If, on the other hand, there is in fact a linear relationship between the two variables (that is, they are *co-integrated*), then the residual η_t from the co-integrating regression

$$x_t = \alpha_0 + \alpha_1 y_t + \alpha_2 T_t + \eta_t \tag{A.1}$$

cannot be an $I(1)$ process. The Dickey-Fuller unit root test is applied to detect this possibility.

In general, we cannot reject the hypothesis that the individual almond-price series have unit roots. For each of the price series used in Chapter 5, plus the series of average export prices for the United States, we used OLS to estimate the equations

$$\Delta p_t = \rho p_{t-1} + \alpha + \gamma T_t + \epsilon_t. \tag{A.2}$$

If the price series is $I(1)$, then the estimated $\hat{\rho}$ should be close to zero, while if the process p_t is stationary the estimate should be significantly negative. Since the distribution of the t statistic for this regression is non-standard, we calculated critical values using the formula in MacKinnon (1991). The estimated parameters and the associated t statistics are listed in Table A.1. Only in the case of the U.S. farmgate price can we reject the unit-root hypothesis at the 5 percent significance level, while the average price of imports for Great Britain and Japan show weaker evidence of stationarity (the unit-root hypothesis is rejected at the 10 percent level).

The next step in the investigation is the estimation of co-integrating regression equations between the various pairs of prices, using the form of equation (A.1). Table A.2 contains the principal results from these regressions. If the series are in fact stationary, then these regressions provide useful direct evidence of the relationships between these series. We report only the estimated price parameters $\hat{\alpha}_1$ and the R^2 statistics; since the standard-error estimates for most of these equations may be biased downwards (if the processes are in fact $I(1)$), we do not report either these estimates or the related t statistics. If the processes are not $I(1)$, then the good fit of the equations and the estimated coefficients (close to 1) are strong evidence for the LOP. We take the estimated coefficients and the close fits reported in Table A.2 as evidence for a single price in the almond market, provided that the price series are not $I(1)$.

If they are $I(1)$, then the LOP holds if the series are co-integrated. Suppose the series are not co-integrated, which in turn implies that there are persistent

Table A.1: Unit-Root Tests on Individual Price Series, 1962–89

$$\Delta p_t = \rho p_{t-1} + \alpha + \gamma t + \epsilon_t$$

	$\hat{\rho}$	t
p^{FARM}	-0.86	-4.19**
xp^{SPA}	-0.51	-2.87
xp^{ITA}	-0.50	-2.82
xp^{USA}	-0.45	-2.60
mp^{GER}	-0.49	-2.75
mp^{FRA}	-0.47	-2.70
mp^{GBR}	-0.66	-3.42*
mp^{NLD}	-0.50	-2.76
mp^{ITA}	-0.41	-2.47
mp^{JPN}	-0.71	-3.53*

Notes: * and ** indicate rejection of $H_0 : \rho = 0$, at the 10% and 5% significance levels respectively. Critical values are (10%) −3.23 and (5%) −3.59, calculated from MacKinnon (1991).

independent movements in the various prices series. First, under the hypothesis of independent $I(1)$ price series, the residuals from (A.1) should exhibit positive serial correlation. The co-integrating regression Durbin-Watson statistic (CRDW) should, in fact, be close to zero. Critical values of the CRDW have been calculated for large sample sizes; they are not, however, useful for the small samples of the present model. Instead, we use the CRDW in the conventional manner, to identify serial dependence of the residuals from the co-integrating regression, which would bias the calculated t statistics. In the absence of evidence to the contrary, we then follow the Engle-Granger (1987) procedure of testing the significance of the coefficients from the Dickey-Fuller equations

$$\Delta u_t = \pi u_{t-1} + \epsilon_t,$$

where u_t are the calculated residuals from the co-integrating regressions (A.1). We use the formulas from MacKinnon (1991) to calculate the critical values to be used to test whether the estimates $\hat{\pi}$ are significantly different from zero, in which case we can reject the hypothesis that the price series are not co-integrated, in favor of the proposition that the price-series pairs are linearly interdependent.

Table A.3 lists results for co-integration tests between export prices and between export prices and the U.S. farmgate price. There is evidence of a statistical linkage between average prices received by Italian and Spanish exporters. The residuals from the co-integrating regressions for Spanish and Italian average export prices appear not to be serially correlated, as evidenced both by the CRDW statistics and the t statistics from the Dickey-Fuller regressions. The U.S. average export prices are tied in less well: we reject the hypothesis of no serial correlation in the residuals of the co-integrating equations. However, the prices received by farmers appear to be strongly linked with both European export prices and U.S. export prices. Whether the different behavior of the U.S. export price series is a consequence of the timing of exports, or of other structural conditions in the almond market, needs further investigation.

Table A.2: Regression Coefficients and R^2 Statistics from Price Co-integrating Equations, 1962–89

$$p_{At} = \alpha_0 + \alpha_1 p_{Bt} + \alpha_3 t + \eta_{ABt}$$

(1)	(2)	(a) $\hat{\alpha}_1$	(a) R^2	(b) $\hat{\alpha}_1$	(b) R^2
xp^{SPA}	xp^{ITA}	1.12	0.98	0.84	0.98
xp^{USA}	xp^{ITA}	0.69	0.88	0.94	0.91
xp^{SPA}	xp^{USA}	1.18	0.93	0.65	0.92
p^{FARM}	xp^{USA}	0.41	0.63	0.82	0.77
p^{FARM}	xp^{ITA}	0.42	0.70	1.13	0.86
xp^{SPA}	p^{FARM}	1.25	0.83	0.35	0.68
mp^{GER}	mp^{NLD}	0.90	0.99	1.06	0.99
mp^{GER}	mp^{ITA}	0.76	0.94	1.08	0.93
mp^{GER}	mp^{FRA}	0.92	0.99	1.04	0.98
mp^{GER}	mp^{GBR}	0.86	0.97	1.05	0.97
mp^{GER}	mp^{JPN}	0.80	0.94	1.01	0.94
mp^{NLD}	mp^{ITA}	0.81	0.94	0.98	0.92
mp^{NLD}	mp^{FRA}	0.99	0.99	0.97	0.99
mp^{NLD}	mp^{GBR}	0.90	0.95	0.94	0.95
mp^{NLD}	mp^{JPN}	0.83	0.93	0.90	0.92
mp^{ITA}	mp^{FRA}	1.02	0.94	0.82	0.94
mp^{ITA}	mp^{GBR}	0.94	0.90	0.81	0.92
mp^{ITA}	mp^{JPN}	0.88	0.88	0.78	0.90
mp^{FRA}	mp^{GBR}	0.88	0.94	0.95	0.95
mp^{FRA}	mp^{JPN}	0.81	0.90	0.90	0.91
mp^{GBR}	mp^{JPN}	0.94	0.97	0.98	0.97
xp^{USA}	mp^{GER}	0.87	0.98	1.08	0.98
xp^{USA}	mp^{FRA}	0.80	0.97	1.13	0.97
xp^{USA}	mp^{JPN}	0.69	0.91	1.08	0.92
p^{FARM}	mp^{GER}	0.32	0.58	0.80	0.76
p^{FARM}	mp^{FRA}	0.36	0.65	1.02	0.78
p^{FARM}	mp^{JPN}	0.23	0.53	0.72	0.73

Notes: Columns (a): dependent variable in column (1), independent variable in column (2). Columns (b): dependent variable in column (2), independent variable in column (1).

Table A.3: Test Statistics for Cointegration among Export Prices and the U.S. Farm Price, 1962–89

Dependent variable:	Independent variable: px^{ITA}	px^{SPA}	px^{USA}	p^{FARM}
px^{ITA}	–	1.48†	0.90‡	1.42
	–	[−3.71]	[−2.50]	[−3.72]
px^{SPA}	1.50†	–	1.16‡	1.57
	[−3.76]	-	[−3.19]	[−4.10]
px^{USA}	0.80‡	1.04‡	–	1.51†
	[−2.26]	[−2.91]	-	[−3.96*]
px^{ITA}	2.11†	2.25†	2.30†	
	[−5.45***]	[−5.80***]	[−5.94***]	

Notes: Cointegrating Regression Durbin-Watson statistic (*CRDW*) above, t statistic from Dickey-Fuller regression in brackets below. †*CRDW* is above the 5% upper limit. ‡$CRDW < d_L(5\%)$. *,**,*** Engle-Granger tests reject no cointegration at 10%, 5%, and 1% levels respectively (critical values are, for 27 observations, −3.80 (10%), −4.35 (5%), and −5.33 (1%), calculated from MacKinnon (1991)).

Table A.4 reports the results from similar tests performed on the average import prices for the importing countries whose demands are analyzed in this chapter. Overall, the picture that emerges is one of a well-integrated market. Prices move together closely, and deviations from LOP behavior are random and temporary. The only possible exception to this rule is Italy, which is also the only significant almond producer in the group. Otherwise, the CRDW statistics are generally satisfactory, while the coefficients in the Dickey-Fuller equations are sufficiently large to permit the rejection of the hypothesis of no co-integration, often at the 1 percent level.

A picture emerges of an industry in which purchasers exercise no market power, but in which competition between sellers may be imperfect, permitting sustained independent deviations in prices received by exporters in different countries. To investigate the phenomenon further, we investigate the relationship between the prices received by U.S. exporters, the prices received by U.S. growers, and the average prices paid by almond importers in three major markets. The results from these tests are in Table A.5. Again, U.S. farmgate prices show no statistical independence from overseas prices, with the hypothesis of no co-integration rejected at either the 5 percent or 1 percent level. The evidence from U.S. export prices is weaker, and does not reject the independence hypothesis in the case of France. Overall, it appears that U.S. growers, at least, are well linked to overseas markets.

Table A.4: Test Statistics for Cointegration among Import Prices, 1962–89

Dependent variable:	Independent variable: mp^{GER}	mp^{FRA}	mp^{GBR}	mp^{ITA}	mp^{JPN}	mp^{NLD}
mp^{GER}		2.66† [−7.53***]	1.60† [−4.23**]	1.46 [−3.87**]	1.15 [−3.42*]	1.93† [−4.95***]
mp^{FRA}	2.62† [−7.28***]		2.37† [−6.28***]	1.10 [−3.23*]	1.46† [−3.99**]	1.94† [−5.08***]
mp^{GBR}	1.94† [−5.03***]	2.76 [−7.82***]		2.22† [−5.71***]	1.27 [−3.57*]	2.36† [−6.17***]
mp^{ITA}	1.29 [−3.53*]	0.97 [−2.98]	1.71† [−4.39***]		1.41 [−3.73**]	1.13 [−3.15]
mp^{JPN}	1.56† [−4.28**]	1.91† [−5.10***]	1.33 [−3.71**]	1.99† [−5.51***]		1.91† [−5.04***]
mp^{NLD}	1.95† [−4.98***]	2.00† [−5.27***]	2.04† [−5.22***]	1.32 [−3.51*]	1.52 [−4.10**]	—

Notes: Cointegrating Regression Durbin-Watson statistic (*CRDW*) above. t statistic from Dickey-Fuller regression in brackets below. †*CRDW* is above the 5% upper limit. ‡*CRDW*< d_L(5%). *,**,*** Engle-Granger tests reject no cointegration at 10%, 5%, and 1% levels respectively (critical values are, for 27 observations, −3.80 (10%), −4.35 (5%), and −5.33 (1%), calculated from MacKinnon (1991)).

Table A.5: Test Statistics for Cointegration between U.S. Prices and Selected Import Prices, 1962–89

	xp^{USA} (a)	xp^{USA} (b)	p^{FARM} (a)	p^{FARM} (b)
mp^{GER}	1.58† [−4.17**]	1.50† [−4.00*]	1.56† [−4.28**]	2.36† [−6.16***]
mp^{FRA}	1.11‡ [−3.20]	1.08‡ [−3.10]	1.58† [−4.16**]	2.34† [−6.11***]
mp^{JPN}	1.89† [−4.93***]	1.40 [−3.80*]	1.95† [−4.99***]	2.25† [−5.79***]

Notes: In columns (*a*), the foreign import price is the dependent variable in the cointegrating regression equation. In columns (*b*), the U.S. price is the dependent variable. Cointegrating Regression Durbin-Watson statistic (*CRDW*) above, t statistic from Dickey-Fuller regression in brackets below. †*CRDW* is above the 5% upper limit. ‡*CRDW*< d_L(5%). *,**,*** Engle-Granger tests reject no cointegration at 10%, 5%, and 1% levels respectively (critical values are, for 27 observations, −3.80 (10%), −4.35 (5%), and −5.33 (1%), calculated from MacKinnon (1991)).

B. ENTRANT AND INCUMBENT SUPPLY RESPONSE

A marketing order that raises price and profits above normal levels faces expanded production from (A) current industry members, (B) new entrants from within the area under the order's control, and (C) producers outside the order's control. Econometric studies of supply response will generally capture the joint response from (A) and (B); data ordinarily will not permit entrant and incumbent response to be differentiated. This appendix discusses conceptual modeling to decompose entrant response from incumbent response.

Assume growers and potential growers under an order's control are arrayed on a continuum indexed on $[0, 1]$, each with a fixed value A_0 of total acreage. Land is not homogeneous. Each farmer has some land better suited to growing the crop *ceteris paribus*. Thus, yield per acre for any grower i, Y_i, is a decreasing function of the number of acres, B_i, planted to the crop. Let $Y_i = f_i(B_i, t)$, $f_i' < 0$ define the relationship between yield and planted acreage for each grower $i \in [0, 1]$, where t denotes the dependency of yield upon the age of the investment.[1] In modeling $f_i(\cdot)$, assume that $f_i(\cdot) = \theta_i f(\cdot)$ for all i, where θ_i is a shift parameter, so that $\theta_j > \theta_i$ implies that j's acreage is absolutely more suited to growing the product than i's acreage and/or that j is an absolutely more productive manager of production than i.

Supply of the marketing-order crop is dynamic because growing the crop requires a nonfungible investment of K per acre in "establishment" costs, and the useful life of this investment extends over multiple periods. These costs, for example, may be the costs of establishing a grove of trees for a perennial fruit or nut crop, or they may refer to costs of establishing irrigation infrastructure for an annual crop. To simplify the exposition, it is assumed that the investment K has a useful life of T years and begins yielding returns in the period after the investment is made. Moreover, we assume that the investment does not depreciate over its useful life. Thus $f(B_i, t') = f(B_i, t'')$ for all $t', t'' = 1, \ldots, T$. Given this depreciation structure the model need make no assumptions about the age structure of existing investment because (i) by assumption age does not affect yield and (ii) replacement costs for depreciated investment are not a function of marketing order behavior because these costs would be borne in any event under the competitive steady-state equilibrium. Only the costs of net additional investments should be attributed to cartel behavior.

All actual and potential growers must develop a forecast of the revenue stream over the life of their potential investments. We assume that, in developing these forecasts, actual and potential growers act as price takers; they perceive that their potential future production has no effect on their forecast of the future price path. The investment decision depends upon the revenue flow over the useful life of the investment. Selling price per unit is denoted as $P(t)$. Marginal costs of tending and harvesting the crop are assumed to be a constant amount c per unit of output, and c is also assumed to be constant over the life of an investment. The expected, cumulative net discounted marginal revenue per acre is then expressed for each grower as

$$\begin{aligned} NMR_i(B_i, \theta_i, p) &= \theta_i f(B_i) \int_1^T (P(t) - c)\, e^{-rt} dt \quad \text{for all } i \in [0,1] \qquad \text{(B.1)} \\ &= \theta_i f(B_i) R\,(P(t), c, r)\,, \end{aligned}$$

where $R(\cdot)$ is the discounted value of the unit flow of sales over the life of the investment, and r is the real discount rate.

[1] An assumption of this sort is necessary to achieve interior solutions to the acreage optimization problem. Alternatively, one can assume quadratic adjustment costs as acreage expands (Dorfman and Heien 1989).

Index growers on the continuum in reverse ranking of their θ_i values so that the grower with the highest θ value has the lowest index number. It then follows that growers will enter production in the sequence of their ordering in the continuum. To express θ_i, define units so that the maximum value for θ is $\theta_{max} = 1$, and the lowest value of θ is $\theta_{min} = k\theta_{max}$, $0 < k < 1$. Assume further that θ_i is distributed uniformly over $[k, 1]$. Therefore, $\theta_0 = 1$, $\theta_1 = k$, and θ is distributed across $[0, 1]$ with frequency $1/(1-k)$.

In addition to K, each entrant incurs a fixed entry cost $E > 0$ upon entering production of the crop.[2] Define

$$\begin{aligned} B_i^* &= \text{argmax}\left\{\pi_i = \theta_i R(P(t), c, r)\int_0^{B_i} f(B_i)dB_i - KB_i - E\right\}, \text{ if } \Pi(B_i^*) \geq 0, \\ &= 0 \text{ otherwise.} \end{aligned} \qquad \text{(B.2)}$$

Let $P^c(t)$ denote the trajectory of expected prices in the absence of any market intervention and define $R^c(P^c(t), c, r)$ as the discounted cumulative net unit revenue stream given that trajectory. Next define $\theta^*(R^c) \in (k, 1)$ such that

$$R^c(P^c(t), c, r)\theta^* \int_0^{B^*(\theta^*)} f(B_i)dB_i - KB^*(\theta^*) = E. \qquad \text{(B.3)}$$

Given values for K and E, $R = R^c$ defines the set of producers at time $t = 0$. All growers with θ values in $[\theta^*, 1]$ produce the crop and all those with θ values in $[k, \theta^*)$ do not. Expected harvest for any grower is

$$Q_i(t) = B_i^* Y_i^0(B_i^*, \theta_i), \qquad \text{(B.4)}$$

where Y_i^0 is average yield, defined as

$$Y_i^0 = \frac{\theta_i}{Bi^*}\int_0^{B_i^*} f(B_i)dB_i = (\theta_i/B_i^*)F(B_i^*). \qquad \text{(B.5)}$$

Combining (B.4) and (B.5) obtains

$$Q_i = \theta_i F(B_i^*(\theta_i, R, K, E)) \qquad \text{(B.6)}$$

Total supply, $Q_1(t)$, for the current producers, given R^c, is[3]

$$Q_1(R^c) = \frac{1}{1-k}\int_{\theta^*(R^C)}^1 Q_i\, d\theta = \frac{1}{1-k}\int_{\theta^*(R^C)}^1 \theta_i\, F(B_i^*(\theta_i, R^C))\, d\theta. \qquad \text{(B.7)}$$

Now we can decompose supply response to a discounted revenue change according to output by new entrants versus expansion by current producers by using Liebnitz's rule:

$$(1-k)\frac{dQ}{dR} = -Q_i(\theta^*(R), R)\frac{d\theta^*(R)}{dR} + \int_{\theta^*}^1 \left(\frac{\partial Q_i(\theta_i, R)}{\partial R}\right) d\theta, \qquad \text{(B.8)}$$

$$(1-k)\frac{dQ}{dR} = -\theta^* F(B^*(\theta^*, R), t)\frac{d\theta^*(R)}{dR} + \theta_i f(B_i^*)\int_{\theta^*}^1 \left(\frac{\partial B_i(\theta_i, R)}{\partial R}\right) d\theta, \qquad \text{(B.8')}$$

[2]Whether E is also sunk (nonrecoverable) is only important if the model is used to analyze questions of exit (removals).

[3]Note that the distinction between extant producers and entrants must be determined based upon market equilibrium in the absence of a marketing order. Values for B^* must be recomputed given the presence of a marketing order.

where (B.8′) is obtained by substituting from (B.6) for $Q_i(\theta^*, p)$, using (B.6) to simplify the integral in (B.8), and recognizing that $\theta_i f(B_i^*)$ =constant, so that it can be transferred through the integration operation.[4]

The first expression in (B.8′) is the production response by new entrants. Because $E > 0$, new entrants enter production discontinuously. The second expression indicates the expansion by current producers. This expansion consists merely of the yield of a marginal acre (constant across current producers) times the change in acreage for each current grower, all aggregated across the current growers in the continuum.

The opportunity of an agricultural cartel to exercise market power depends importantly upon the total magnitude of dQ/dR as well as the relative magnitudes of the two expressions that comprise dQ/dR. The above model reduces the relative output response into one expression which includes one key function, the yield function $f(\cdot)$, and four key parameters: k which measures the efficiency dispersion in the industry, R the net revenue per unit, K the fixed establishment cost per acre, and E the sunk entry cost. For example, if k is large, it implies that farmers are equally suited to growing the crop in question. This means that the frequency of any θ value is high and that the absolute entry response to a change in price will be great. However, k does not affect the relative entry response. Similarly, greater values of E imply that the minimum scale of entry in the industry is large and that the output of each entrant stimulated by $dR > 0$ will be large. This behavior induces the paradoxical result that industries with a high magnitude of entry cost are actually more vulnerable to disruption of cartel power through outside entry because entrants enter production at a large scale. The larger is R relative to K, the more profitable is the industry. In turn, high R/K implies a low value for θ^* and a relatively greater incumbent response.

For purposes of constructing the empirical dynamic optimization model, the yield function $f(B_i)$ was assumed to be linear. Yields can also be normalized to obtain the following yield function:

$$f(B_i) = 1 - bB_i \text{ for all } i \in [0, 1].$$

A normalization can also be chosen for the monetary measures. Normalizing on per-unit establishment costs K, we define $P = R/K$ as the normalized, discounted per-unit revenue, and $E = E/K$ as normalized entry costs.

Given these specifications, the interior solution for B^* can be solved from (B.2) to obtain

$$B_i^* = \frac{P\theta_i - 1}{bP\theta_i},$$

and

$$\frac{dB_i^*}{dP} = \frac{1}{bP^2\theta_i}.$$

(B.3) can then be solved to yield θ^*:

$$\theta^* = \frac{bE' + 1 + \sqrt{b^2E'^2 + 2bE'}}{P}$$

and

$$\frac{d\theta^*}{dP} = \frac{-\theta^*}{P}.$$

From (B.4) output can be expressed as:

$$Q_i = \frac{P^2\theta_i^2 - 1}{2bP^2\theta_i}.$$

[4]Note that the term $\theta_i f(B_i^*)$ is simply the yield of the marginal acre, which is constant across all *current* growers.

Substituting θ^* into this expression in place of θ_i obtains output for the marginal producer:

$$Q_i(\theta^*) = \frac{E'}{b} + \frac{\sqrt{b^2 E'^2 + 2bE'}}{b^2 P E' + bP\left(1 + \sqrt{b^2 E'^2 + 2bE'}\right)}.$$

C. DATA TABLES

The tables on the following pages contain the data that were used in the econometric work in this monograph. The sources are discussed in more detail in the text.

C2.1: California Almond Acreage by Category, Production, Yield, Rainfall, 1950–92

YEAR	YB_t	MB_t	OB_t	B_t	Q_t	y_t	$FEBRAIN_t$
1950	14.9	36.1	39.5	90.5	45,240	0.50	2.33
1951	15.7	37.3	37.7	90.7	51,240	0.56	2.67
1952	16.4	38.3	36.7	91.4	43,680	0.48	1.62
1953	16.6	39.1	36.6	92.2	46,320	0.50	0.19
1954	19.8	39.9	32.9	92.6	51,840	0.56	1.91
1955	19.7	41.2	28.4	89.4	45,960	0.51	0.99
1956	17.4	41.2	30.0	88.6	70,320	0.79	1.56
1957	15.7	40.7	31.7	88.2	45,000	0.51	2.48
1958	15.3	40.4	33.8	89.5	23,760	0.27	6.68
1959	11.3	42.8	35.0	89.2	99,360	1.11	4.23
1960	11.1	43.3	34.8	89.1	63,600	0.71	2.88
1961	16.0	39.1	34.1	89.3	79,680	0.89	1.57
1962	20.5	37.4	35.1	93.1	57,600	0.62	6.72
1963	24.4	36.5	37.0	97.8	72,360	0.74	2.53
1964	27.8	36.3	37.7	101.8	90,480	0.89	0.09
1965	30.0	38.1	38.4	106.5	87,480	0.82	0.68
1966	30.6	41.5	40.7	112.8	102,120	0.91	1.71
1967	32.9	43.0	44.9	120.9	91,920	0.76	0.34
1968	38.6	45.1	45.7	129.5	89,400	0.69	2.25
1969	48.6	47.8	48.7	145.1	146,400	1.01	6.31
1970	65.1	51.6	49.1	165.8	148,800	0.90	1.64
1971	77.1	52.3	53.8	183.1	160,800	0.88	0.25
1972	83.8	56.3	57.9	197.9	150,000	0.76	0.86
1973	89.4	66.3	57.7	213.4	160,800	0.75	4.92
1974	92.8	80.7	56.7	230.3	226,799	0.98	1.22
1975	87.9	101.4	58.6	247.9	191,999	0.77	3.73
1976	84.0	118.1	54.7	256.7	285,291	1.11	2.70
1977	93.2	129.0	51.3	273.4	313,085	1.15	0.73
1978	109.6	139.7	54.2	303.6	181,027	0.60	3.60
1979	113.9	153.0	54.5	321.4	376,027	1.17	4.21
1980	106.3	165.0	55.5	326.8	321,797	0.98	5.03
1981	97.0	174.2	55.0	326.2	407,444	1.25	1.19
1982	85.3	192.1	60.9	338.3	346,730	1.02	1.61
1983	77.2	218.7	60.3	356.2	241,893	0.68	4.83
1984	82.6	233.9	63.1	379.6	586,910	1.55	1.51
1985	111.7	232.7	64.9	409.2	462,263	1.13	0.82
1986	128.5	222.6	61.6	412.7	251,597	0.61	5.95
1987	124.8	212.3	73.8	410.9	659,676	1.61	2.65
1988	106.8	218.9	81.5	407.1	590,007	1.45	0.54
1989	84.6	232.7	92.0	409.4	488,508	1.19	1.14
1990	51.1	255.0	105.2	411.3	656,189	1.60	1.60
1991	35.4	258.3	74.5	368.3	485,928	1.32	1.93
1992	38.2	249.1	69.5	356.8	550,000	1.54	5.76

NOTES: YB_t = thousands of acres of young bearing trees (4–9 years old as of May 31), MB_t = thousands of acres of mature bearing trees, (10–20 years old), OB_t = thousands of acres of old bearing trees, (over 20 years old), B_t = thousands of acres of bearing trees, Q_t = total production of almonds in thousands of pounds kernel-weight, and y_t = average yield per bearing acre. YB_t and MB_t trees are arrived at by summing over the appropriate lags of the plantings series (see Table C3.1). $OB_t = B_t - YB - MB$, where B_t, bearing acreage, is taken directly from the California Agricultural Statistical Service (CASS) data. $FEBRAIN_t$ is the sum of February rainfall (inches) measured at the Chico, Modesto, and Fresno airports, divided by 3.

C3.1: Plantings, Removals, and Expected Net Present Value of California Almond Acreage, 1961–90

YEAR	PL_t	R_t	$ENPV_t$
1961	6,244	6,184	4,230
1962	6,948	2,138	6,061
1963	8,219	1,011	4,539
1964	11,453	1,752	5,436
1965	15,779	1,542	4,840
1966	22,701	692	4,888
1967	18,900	89	5,697
1968	14,948	2,898	5,953
1969	17,101	109	1,122
1970	19,168	2,050	1,924
1971	17,816	1,594	2,462
1972	14,936	120	7,198
1973	24,154	1,570	28,565
1974	33,564	2,350	11,040
1975	23,419	127	3,893
1976	10,247	6,143	3,798
1977	5,658	7,478	11,815
1978	12,375	3,389	25,512
1979	25,502	5,641	22,751
1980	28,489	4,821	14,170
1981	38,680	6,248	-6,516
1982	22,017	264	-4,330
1983	8,080	7,599	-3,159
1984	6,653	5,147	-5,759
1985	5,531	9,002	-4,682
1986	4,041	18,586	9,893
1987	5,239	9,856	44
1988	8,851	10,410	188
1989	7,575	3,297	-5,023
1990	4,230	2,140	-6,012

NOTES: PL_t = plantings and R_t = removals, in thousands of acres. $ENPV_t$ is the expected net present value of an acre of newly-planted almonds, in 1972 dollars, exclusive of the resale value of the land. PL_t is the highest acreage reported as planted in year t from CASS surveys of standing acreage by year of planting. R_t is calculated from B_t (see Table C2.1) and PL_t to satisfy $B_t = B_{t-1} + PL_{t-4} - R_t$. See footnote 2 of Chapter 2.

C3.2: Prices, Costs and Investment Parameters for California Almonds, 1951–1990

YEAR	P_t	C_t	$Defl_t$	ITC_t	MTR_t	$depr_t$	r_t
1961	0.467	257	46.36	0.070	0.432	30	-0.0017
1962	0.545	261	47.40	0.070	0.439	30	0.0022
1963	0.492	263	48.15	0.070	0.439	30	0.0006
1964	0.525	266	48.89	0.070	0.439	30	0.0015
1965	0.514	268	50.23	0.070	0.447	30	0.0018
1966	0.508	273	52.01	0.070	0.449	30	0.0001
1967	0.485	242	53.35	0.000	0.464	30	-0.0057
1968	0.497	247	56.02	0.070	0.469	30	-0.0040
1969	0.505	408	59.14	0.070	0.469	30	-0.0068
1970	0.538	426	62.41	0.000	0.475	30	-0.0118
1971	0.542	445	65.98	0.070	0.475	20	-0.0215
1972	0.654	466	69.10	0.070	0.485	20	-0.0285
1973	1.242	489	73.56	0.070	0.484	20	-0.0260
1974	0.750	420	80.24	0.070	0.484	20	-0.0255
1975	0.617	514	88.12	0.070	0.484	20	-0.0353
1976	0.675	616	93.77	0.100	0.484	20	-0.0507
1977	0.858	649	100.01	0.100	0.486	20	-0.0511
1978	1.402	816	107.29	0.100	0.486	20	-0.0442
1979	1.479	842	116.80	0.100	0.486	20	-0.0389
1980	1.421	950	127.35	0.100	0.486	20	-0.0333
1981	0.754	1093	139.68	0.100	0.498	5	-0.0276
1982	0.909	1153	148.60	0.080	0.399	5	-0.0213
1983	1.006	1203	154.40	0.080	0.445	5	-0.0290
1984	0.748	1214	160.04	0.080	0.336	5	0.0042
1985	0.774	1249	164.80	0.080	0.338	5	0.0120
1986	1.857	1037	169.11	0.000	0.330	5	0.0124
1987	0.967	993	174.46	0.000	0.337	10	0.0207
1988	1.015	1033	180.25	0.000	0.337	10	0.0214
1989	0.998	1095	187.68	0.000	0.340	10	0.0168
1990	0.900	1140	195.41	0.000	0.340	10	0.0125

NOTES: P_t = price of almonds ($/pound, kernel weight), C_t = average variable cost per acre ($/acre), in nominal terms. $Defl_t$ is the GNP deflator, 1977=0. ITC_t is the investment tax credit for each $1 of investment. MTR_t is the average marginal tax rate, calculated as the top marginal California and Federal rates, divided by two, plus the self-employment tax rate. $depr_t$ is the period over which year t plantings are depreciated for tax purposes. r_t is the real interest rate, calculated as $i_t - \pi_t$, where π_t is the percentage annual growth rate of D_t (the rate of inflation) and i_t is the nominal Standard and Poors long term bond rate.

C3.3: Expected Mature Yields and Establishment Costs for California Almond Acreage, 1961–90, and Olson's Yield Factor for Almonds

YEAR	y_t^M	EC_{1t}	EC_{2t}	EC_{3t}	EC_{4t}	EC_{5t}	s	f_s
1961	1760.1	643.1	363.6	418.7	604.5	711.6	4	0.222222
1962	1774.2	646.1	365.3	420.6	607.3	714.9	5	0.444444
1963	1788.3	650.5	367.8	423.5	611.4	719.8	6	0.666666
1964	1802.4	652.0	368.6	424.5	612.8	721.4	7	0.833333
1965	1816.6	662.3	374.5	431.2	622.5	732.9	8	1.000000
1966	1830.7	618.0	349.4	402.3	580.9	683.8	9	1.000000
1967	1844.8	631.3	356.9	411.0	593.4	698.5	10	1.000000
1968	1858.9	573.6	324.3	373.5	539.2	634.7	11	1.000000
1969	1873.0	603.2	341.1	392.7	567.0	667.5	12	1.000000
1970	1887.1	597.1	328.5	377.0	543.1	629.8	13	1.000000
1971	1901.2	604.6	322.6	369.0	530.1	603.9	14	1.000000
1972	1915.3	613.4	316.3	360.2	515.9	575.4	15	1.000000
1973	1929.5	604.2	299.8	339.7	484.7	526.8	16	1.000000
1974	1943.6	708.1	336.1	378.6	537.8	565.9	17	1.000000
1975	1957.7	791.5	357.0	399.3	564.0	569.3	18	1.000000
1976	1971.8	788.6	335.2	371.4	521.1	497.6	19	1.000000
1977	1985.9	1025.5	406.2	444.9	618.5	546.4	20	1.000000
1978	2000.0	1013.9	368.8	397.8	546.3	429.0	21	1.000000
1979	2014.1	1067.1	349.2	368.8	497.6	319.8	22	1.000000
1980	2028.2	1120.6	320.5	327.9	430.6	179.1	23	1.000000
1981	2042.4	1391.3	332.2	322.9	404.1	0.0	24	1.000000
1982	2056.5	1372.9	349.0	344.2	445.3	0.0	25	1.000000
1983	2070.6	1343.3	363.7	363.8	484.7	0.0	26	0.972222
1984	2084.7	1307.7	377.4	382.5	523.5	0.0	27	0.944444
1985	2098.8	854.3	263.1	270.0	378.5	0.0	28	0.916666
1986	2112.9	798.9	262.9	272.9	391.2	0.0	29	0.888888
1987	2127.0	767.8	270.4	283.7	414.9	0.0	30	0.833333
1988	2141.1	750.0	283.0	300.0	447.0	0.0	31	0.777777
1989	2155.2	782.2	295.1	312.9	466.2	0.0	32	0.722222
1990	2169.4	807.2	304.6	322.9	481.1	0.0	33	0.666666
							34	0.611111
							35	0.555555

NOTES: y_t^M is the expected mature yield of an acre planted in year t, in pounds per acre (in-shell). EC_{st} is the establishment cost of an acre planted in year t, incurred in year s after planting. f_s is Olson's yield factor for almonds, giving the proportion of mature yield (y_t^M) s years after planting.

C4.1: Spanish Almond Yields and Weather in Almond-Producing Regions of Spain, 1959–89

YEAR	y_t^{Irr}	y_t^{Dry}	y_t^{Tot}	JFR_t	FF_t	MAR_t	JR_t
1971	1,187	412	450	48.91	0.14	145.04	0.61
1972	1,320	576	610	65.50	0.29	90.74	0.74
1973	1,090	450	520	36.88	2.14	60.60	13.66
1974	1,286	610	640	41.77	1.00	128.19	10.64
1975	1,267	475	590	49.37	0.00	106.37	0.14
1976	1,484	576	630	44.14	0.14	77.37	16.49
1977	879	275	410	99.16	0.43	35.89	19.49
1978	1,300	529	590	41.09	1.57	59.48	0.17
1979	859	303	340	130.98	1.00	33.34	8.94
1980	961	364	420	143.70	0.71	78.26	0.37
1981	1,530	472	550	33.25	2.71	98.51	7.69
1982	1,371	496	570	81.71	0.86	131.57	1.86
1983	664	255	300	21.18	4.71	16.07	1.30
1984	1,006	368	410	50.71	2.43	63.00	0.13
1985	1,601	434	520	62.00	0.86	34.09	0.26
1986	1,411	315	400	39.85	2.57	63.86	17.00
1987	1,415	354	390	128.29	2.14	9.53	26.43
1988	686	247	290	80.14	2.14	51.52	0.46
1989	1,607	440	560	87.14	1.86	104.00	2.57

NOTES: y_t^{Irr} is yields in irrigated orchards, in-shell kilograms per hectare. y_t^{Dry} is yields of unirrigated trees, in-shell kilograms per hectare. y_t^{Tot} is total yields, in-shell kilograms per hectare. The following weather data are averages from the weather-reporting stations of the Levante and Andalusia regions: JFR_t is average rainfall in centimeters during January and February. FF_t is the average number of frost days recorded during February. MAR_t is average rainfall in centimeters during March and April. JR_t is average rainfall in centimeters during July. The data in this table have been assembled from a variety of Spanish sources which are on file at the U.C. Davis Department of Agricultural Economics.

C4.2: Spanish Almond Acreage, Plantings, Harvests, and Prices; Spanish Agricultural Costs, 1965–89

YEAR	A_t^{SP}	B_t^{SP}	N_t^{SP}	H_t^{SP}	P_t^{SP}	C_t^{SP}	OB_t^{SP}
1965	240.2	215.3	1.6	152.8	19.16	15.93	150.8
1966	242.6	210.7	2.4	155.0	18.90	16.41	150.8
1967	247.3	209.7	4.7	121.7	20.51	16.79	150.8
1968	252.6	222.8	5.3	152.5	22.75	16.95	149.4
1969	266.2	240.0	13.6	108.8	28.49	17.22	150.0
1970	298.7	267.7	32.5	165.8	33.20	17.67	150.1
1971	326.8	262.5	28.1	140.6	30.69	18.49	150.5
1972	396.8	331.9	70.0	234.1	31.48	18.75	150.7
1973	441.8	382.9	45.0	216.4	40.67	20.83	151.0
1974	480.5	420.0	38.7	318.9	45.19	27.12	153.0
1975	500.0	434.8	19.5	255.4	34.54	29.30	153.7
1976	510.6	450.0	10.6	316.6	31.47	64.27	153.3
1977	527.4	461.2	16.8	155.2	51.48	36.53	154.0
1978	532.3	482.8	4.9	306.7	60.00	41.17	154.0
1979	555.7	507.6	23.4	197.5	84.72	46.97	153.8
1980	564.5	515.6	8.8	225.3	85.92	55.91	153.5
1981	565.1	519.5	0.6	307.3	62.26	66.29	155.7
1982	567.7	524.3	2.6	315.3	60.45	73.09	156.2
1983	568.6	526.5	0.9	165.8	103.01	84.59	159.2
1984	570.1	531.4	1.5	236.1	123.28	95.07	161.4
1985	572.8	534.6	2.7	287.0	109.11	100.00	171.4
1986	577.9	539.2	5.1	221.4	147.33	103.80	171.6
1987	582.6	546.9	4.7	250.0	118.90	104.80	172.4
1988	597.7	561.2	15.1	169.7	108.20	106.30	177.6
1989	614.1	581.8	16.4	324.9	85.96	108.90	201.5

NOTES: Acreage data are measured in thousands of hectares. A_t^{SP} is total almond acreage. B_t^{SP} is bearing acreage. N_t^{SP} is net increase in acreage (plantings less removals). H_t^{SP} is almond harvests, in thousands of metric tons, on an in-shell basis. P_t^{SP} is the average farmgate price of almonds in Spain, pesetas per kilogram (in-shell basis). C_t^{SP} is the General Farm Price Index for Spain. OB_t^{SP} is thousands of hectares of trees older than 34 years. The data in this table have been assembled from a variety of Spanish sources, and are on file at the U.C. Davis Department of Agricultural Economics.

C5.1: Harvests, Stocks, Domestic Usage, Net Exports, and Prices of California Almonds, and Net Exports of Spanish Almonds, 1961–91

YEAR	H_t	S_t	d_t^{USA}	NX_t^{USA}	NX_t^{SPA}	p_t^{FARM}
1961	79,680	9,152	70,979	3,773	46,127	0.468
1962	57,600	14,080	52,442	12,710	60,451	0.545
1963	72,360	6,528	53,635	17,937	33,732	0.492
1964	90,480	7,316	70,966	16,849	49,638	0.525
1965	87,480	9,981	67,421	21,352	51,761	0.514
1966	102,120	8,689	78,611	20,012	52,428	0.508
1967	91,920	12,186	80,624	20,552	46,528	0.485
1968	89,400	2,930	71,796	18,134	54,357	0.497
1969	146,400	2,400	104,914	38,017	50,739	0.505
1970	148,800	5,869	79,104	62,085	27,707	0.538
1971	160,800	13,480	99,365	72,341	41,267	0.538
1972	150,000	2,574	78,427	70,928	64,399	0.650
1973	160,800	3,219	99,194	54,936	68,051	1.288
1974	226,799	9,889	102,971	83,590	35,676	0.740
1975	191,999	50,127	126,369	97,088	44,699	0.637
1976	285,291	18,669	161,927	122,269	57,311	0.648
1977	313,085	19,764	167,274	134,963	58,311	0.845
1978	181,027	30,612	65,472	133,865	58,753	1.450
1979	376,027	12,301	247,402	120,778	53,467	1.530
1980	321,797	20,148	121,065	180,796	32,328	1.470
1981	407,444	40,084	210,587	158,705	50,506	0.780
1982	346,730	78,237	186,133	154,907	73,245	0.940
1983	241,893	83,927	176,866	130,337	91,589	1.040
1984	586,910	18,617	301,815	177,904	56,829	0.774
1985	462,263	125,808	252,083	293,170	46,203	0.680
1986	251,597	42,818	47,453	226,737	54,758	1.920
1987	659,676	20,225	355,232	209,498	57,664	1.000
1988	590,007	115,171	218,214	327,839	16,285	1.050
1989	488,508	159,125	283,599	294,305	55,527	1.020
1990	656,189	69,729	252,413	355,110	25,185	0.930
1991	485,928	118,395	279,651	273,003	25,053	1.190

NOTES: H_t is harvests of California almonds, reported in the Almond Board of California Position Reports as Receipts in year t, in thousands of pounds, kernel weight. S_t is uncommitted inventories, calculated as Carryin on July 1 of year t, less commitments. d_t^{USA} is domestic usage, calculated as $d_t^{USA} = H_t + S_t - S_{t+1} - NX_t^{USA}$. NX_t^{USA} is U.S. net exports, in thousands of pounds kernel weight, as reported by the Food and Agriculture Organization (FAO). NX_t^{SPA} is Spanish net exports, in thousands of pounds kernel weight, as reported by FAO, constructed by subtracting the value of shelled and inshell almond imports from the values of inshell and shelled exports, and dividing by the average price of shelled exports. p_t^{FARM} is the average grower return in California per pound (kernel weight) of almond production, from USDA, *Fruit and Tree Nuts*.

C5.2: Almond Usage and Prices, and Filbert Prices, for Germany, France and Great Britain, and Rest-of-World Almond Usage, 1970–91

YEAR	d_t^{DEU}	rp_t^{DEU}	rpf_t^{DEU}	d_t^{FRA}	rp_t^{FRA}	rpf_t^{FRA}	d_t^{GBR}	rp_t^{GBR}	d_t^{RW}
1970	42,487	4.779	3.827	27,860	11.499	9.360	15,688	1.169	18,500
1971	50,289	4.336	3.218	30.293	10.620	8.545	18,669	0.959	21,446
1972	52,500	4.411	2.872	33,115	10.650	8.226	18,940	1.027	12,564
1973	48,704	4.809	2.319	29,687	12.724	7.176	13,221	1.331	5,115
1974	44,709	4.435	2.419	25,644	12.680	8.082	13,016	1.497	10,101
1975	50,355	3.003	2.298	27,811	7.754	7.138	13,247	0.816	28,641
1976	61,500	2.746	2.054	34,751	6.650	6.427	18,801	0.828	41,141
1977	64,306	2.741	2.110	36,658	7.386	7.796	18,146	0.832	58,903
1978	69,985	3.056	2.286	37.275	8.003	7.416	18,995	0.957	39,423
1979	63,451	3.738	2.512	32,857	9.966	8.013	17,778	1.051	32,938
1980	72,617	3.779	3.399	36,524	9.113	9.155	16,676	0.881	44,473
1981	77,536	3.456	3.109	35.412	7.533	8.242	15,988	0.749	52,593
1982	82,227	2.558	2.107	40,086	5.931	6.612	23,397	0.495	43,654
1983	84,374	2.764	2.131	44,502	6.467	7.311	24,081	0.671	44,338
1984	74,363	3.474	2.375	35,763	8.654	7.959	21,649	0.770	63,142
1985	89,284	2.892	3.124	42,648	6.634	9.088	23,382	0.668	110,348
1986	97,827	2.489	2.922	43,517	6.846	7.005	25,972	0.675	42,508
1987	85,527	2.892	2.682	37,436	6.743	7.318	18,799	0.930	47,303
1988	97,908	2.162	2.288	44,731	5.682	6.856	22,943	0.534	78,744
1989	99,968	2.301	1.823	39,973	5.876	4.327	23,593	0.653	112,154
1990	122,265	1.900	1.690	42,697	4.571	3.986	26,161	0.540	110,497
1991	123,339	1.730	1.580	45,758	4.696	3.738	26,544	0.480	25,771

NOTES: d_t^j is net imports of almonds for country j, in thousands of pounds kernel weight, while rp_t^j and rpf_t^j are the average prices of almond imports and filbert imports for country j, calculated as the value of imports (C.I.F port) divided by the physical volume of imports, and measured in real national currency units. The original data are from FAO; prices are converted to national currency units using market exchange rates and deflated using each country's consumer price index, both from the International Monetary Fund (IMF), *International Financial Statistics*. d_t^{RW} is calculated as U.S. net exports plus Spain net exports, less net imports by Germany, France, Great Britain, the Netherlands, Italy, Japan, and Canada, in thousands of pounds kernel weight.

C5.3: Almond Usage and Prices, and Filbert Prices, for Japan, the Netherlands and Canada, 1961–91

YEAR	d_t^{JPN}	rp_t^{JPN}	d_t^{NLD}	rp_t^{NLD}	rpf_t^{NLD}	d_t^{CAN}	rp_t^{CAN}	rpf_t^{CAN}
1961	1,102	1,004	7,787	6.012	8.593	3,417	2.233	0.942
1962	2,110	1,058	6,151	7.477	8.399	3,317	2.805	1.205
1963	2,493	1,093	6,193	8.354	7.925	3,166	3.048	1.202
1964	3,851	989	6,482	8.027	7.841	3,400	3.011	1.042
1965	3,682	952	7,231	7.204	7.263	3,401	2.861	0.997
1966	5,888	867	7,282	7.086	6.836	3,254	2.720	0.979
1967	7,630	875	7,551	6.795	6.552	3,463	2.639	0.983
1968	8,444	833	7,959	6.642	6.166	3,959	2.540	0.982
1969	6,825	795	7,480	7.400	6.979	3,892	2.567	0.957
1970	8,214	770	8,466	7.118	6.049	3,833	2.502	1.045
1971	11,687	707	7,743	6.407	5.251	4,095	2.318	0.888
1972	14,614	625	7,630	6.446	5.015	5,113	2.365	0.774
1973	17,798	686	7,218	7.871	4.286	5,887	3.376	0.932
1974	13,772	807	6,854	6.556	4.464	3,937	3.409	0.964
1975	11,645	502	7,668	4.534	4.219	5,043	2.313	0.897
1976	19,290	437	9,508	3.921	3.582	7,896	1.947	0.838
1977	23,263	387	10,110	3.969	4.032	8,601	2.088	0.945
1978	25,968	373	11,310	4.445	3.860	9,373	2.700	1.019
1979	18,311	545	10,282	5.751	4.356	7,194	3.555	1.034
1980	20,591	548	9,599	5.450	5.285	8,771	3.340	1.578
1981	19,273	467	10,518	4.510	4.932	10,780	2.579	1.083
1982	29,165	348	10,866	3.631	3.699	13,516	1.902	0.912
1983	29,242	370	11,453	4.220	4.018	13,184	2.010	0.863
1984	35,344	384	11,464	5.082	4.461	12,561	2.191	0.821
1985	36,248	306	12,178	4.264	5.302	13,816	1.742	0.742
1986	52,663	298	13,192	4.080	4.004	13,238	2.236	0.889
1987	35,185	361	11,587	4.219	4.147	12,201	2.548	0.941
1988	53,810	199	14,709	3.201	3.902	15,025	1.550	0.741
1989	50,965	190	19,684	3.500	2.559	18,025	1.501	0.672
1990	45,242	211	23,581	2.807	2.376	18,537	1.241	0.632
1991	45,242	·190	21,307	2.623	2.206	19,013	1.107	0.568

NOTES: d_t^j is net imports of almonds for country j, in thousands of pounds kernel weight, while rp_t^j and rpf_t^j are the average prices of almond imports and filbert imports for country j, measured in real national currency units. The original data are from FAO; prices are converted to national currency units using market exchange rates and deflated using each country's consumer price index, both from IMF, *International Financial Statistics*.

C5.4: Imports, Exports, Harvests, and Prices of Almonds for Italy, 1961–91

YEAR	IMP_t^{ITA}	EXP_t^{ITA}	H_t^{ITA}	rp_t^{ITA}
1961	397	84,540	65,458	3,166.9
1962	220	59,800	52,420	3,695.4
1963	516	52,584	57,222	4,441.2
1964	683	65,673	69,214	4,027.5
1965	311	60,413	64,077	3,826.3
1966	280	67,730	66,849	3,941.8
1967	401	70,325	69,030	1,495.6
1968	1,448	63,739	66,930	1,393.0
1969	1,166	57,192	61,470	2,595.3
1970	796	36,052	57,180	3,188.2
1971	3,549	34,162	45,360	3,268.5
1972	12,255	21,404	39,510	3,417.6
1973	10,097	14,740	34,260	4,679.1
1974	6,358	5,126	33,450	4.672.1
1975	3,818	6,442	28,890	3,021.1
1976	2,760	16,067	38,010	2,726.8
1977	1,508	28,221	47,640	2,684.7
1978	3,175	22,886	44,550	3,026.8
1979	7,132	15,699	36,750	3,737.2
1980	11,508	7,635	41,070	3,770.8
1981	2,553	15,441	49,860	3,222.2
1982	3,997	18,757	42,480	2,287.6
1983	3,245	32,494	44,460	2,336.0
1984	4,674	24,226	36,450	2,860.7
1985	17,624	6,155	30,555	2,005.4
1986	9,109	16,532	41,640	2,117.2
1987	25,975	6,852	35,367	1,994.5
1988	24,731	8,479	33,344	1,846.2
1989	19,659	12,452	28,327	1,952.1
1990	25,828	4,670	29,224	1,496.7
1991	26,795	5,049	42,443	1,545.1

NOTES: IMP_t^{ITA} and EXP_t^{ITA} are the volume of Italian imports and exports of almonds, respectively, expressed in thousands of pounds (kernel weight), calculated by dividing the value of Italian imports and exports of almonds by the average price of Italian imports and exports of shelled almonds. H_t^{ITA} is Italian almond harvests, in thousands of pounds kernel weight. rp_t^{ITA} is the average price of Italian imports of shelled almonds. All data are from FAO.

C5.5: Real Per-Capita Private Domestic Consumption Expenditures, for the United States, Germany, France, the Netherlands, Great Britain, Italy and Japan, and Total Private Domestic Consumption Expenditures for Canada, 1961–91

YEAR	ry_t^{USA}	ry_t^{DEU}	ry_t^{FRA}	ry_t^{NLD}	ry_t^{GBR}	ry_t^{ITA}	ry_t^{JPN}	rY_t^{CAN}
1961	6,108.3	6,939.4	15,629.4	8,252.5	1,768.0	3,242.5	415.8	104.1
1962	6,340.1	7,233.4	16,366.0	8,668.7	1,784.8	3,457.7	450.7	108.9
1963	6,485.6	7,349.2	17,321.0	9,192.6	1,851.4	3,714.1	483.8	116.7
1964	6,771.4	7,650.6	18,166.8	9,719.5	1,899.9	3,772.3	539.3	122.8
1965	7,043.9	8,065.9	18,706.1	10,104.3	1,921.4	3,859.3	596.6	130.0
1966	7,184.2	8,256.3	19,595.9	10,269.7	1,951.3	4,133.4	648.2	137.0
1967	7,430.6	8,295.7	20,479.3	10,636.7	1,987.2	4,358.2	706.9	143.1
1968	7,798.1	8,646.2	21,123.9	11,104.3	2,035.7	4,544.6	758.4	150.0
1969	7,951.4	9,295.2	22,568.3	12,652.3	2,036.7	4,842.0	820.0	157.3
1970	7,962.2	9.961.4	22,569.7	13,520.3	2,072.7	5,364.8	888.6	160.5
1971	8,242.5	10,420.8	23,563.0	13,853.8	2,110.3	5,549.5	906.6	169.5
1972	8,573.2	10,831.0	24,547.9	14,239.1	2,217.2	5,745.4	982.6	181.1
1973	8,196.5	11,039.5	25,694.6	14,767.0	2,305.2	6,267.7	1,048.6	192.7
1974	7,778.1	11.114.4	26,063.5	15,198.6	2,296.8	6,582.4	1,015.5	203.0
1975	7,842.0	11,544.2	26,681.9	15,537.6	2,270.6	6,541.2	1,044.7	212.1
1976	8,408.7	12,012.7	27,965.2	16,210.1	2,259.0	6,904.6 .	1,068.2	225.7
1977	8,715.0	12,544.6	28,644.7	16,827.7	2,230.9	7,099.1	1.094.2	231.4
1978	8,757.4	13,046.0	29,560.1	17,510.8	2,380.2	7,387.7	1.145.3	236.1
1979	8,712.5	13.463.3	30,314.3	17.928.9	2,482.2	7,887.4	1,208.1	241.6
1980	8,764.7	13,658.2	30,532.7	17,856.5	2,441.3	8,256.9	1,209.2	246.7
1981	8,894.3	13,544.3	30.890.2	17,199.4	2,434.2	8,266.1	1,214.0	249.6
1982	9,061.5	13.310.6	31,706.4	16,831.4	2,456.6	8,386.9	1,258.1	241.7
1983	9,584.3	13.580.0	31,864.7	16,902.8	2,565.5	8.431.4	1,294.0	251.0
1984	9,937.3	13,866.1	32,169.5	16,787.5	2,637.4	8,667.1	1,323.7	261.6
1985	10,404.5	14.085.8	32,828.5	17,107.7	2,718.3	8.888.7	1,361.9	274.5
1986	10,676.0	14,497.9	34.051.8	17,575.1	2,910.8	9,238.5	1,398.4	285.5
1987	10,820.3	15,009.2	34,746.4	18,060.6	3,055.8	9.656.0	1,452.3	296.9
1988	11,118.3	15,323.0	35.673.2	18,158.0	3,260.4	10,106.4	1.510.0	309.4
1989	11,708.8	15,635.1	36,235.4	18,956.6	3.348.1	10.455.7	1,561.0	318.5
1990	11,393.1	16,152.3	37,032.6	19,544.6	3,231.2	10,708.7	1,609.2	320.1
1991	11.205.8	16,600.2	37,158.7	19,920.3	3,204.1	11,157.0	1,628.1	312.3

NOTES: Data are calculated by dividing the Consumption line from the National Accounts by population, and deflating with the Consumer Price Index (CPI). Data are in real national currency units, except for Italy and Japan, which are in thousands of real national currency units, and Canada, which are in billions of real Canadian dollars. All data are from IMF, *International Financial Statistics*.

C5.6: Consumer Prices in the United States, Germany France, the Netherlands, Great Britain, Italy, Japan, and Canada, 1961–91

YEAR	cpi_t^{USA}	cpi_t^{DEU}	cpi_t^{FRA}	cpi_t^{NLD}	cpi_t^{GBR}	cpi_t^{ITA}	cpi_t^{JPN}	cpi_t^{CAN}
1961	30.4	48.3	27.5	26.9	19.3	10.0	25.6	24.9
1962	30.6	49.7	28.9	27.5	20.1	10.5	27.2	25.2
1963	31.1	51.2	30.4	28.4	20.5	11.2	29.4	25.6
1964	31.5	52.4	31.3	30.0	21.2	11.9	30.4	26.1
1965	32.2	54.1	32.2	31.8	22.2	12.4	32.5	26.7
1966	33.8	56.0	33.0	33.6	23.0	12.7	34.1	27.7
1967	34.1	56.9	33.9	34.8	23.6	13.2	35.5	28.7
1968	35.3	57.8	35.5	36.1	24.7	13.4	37.4	29.9
1969	37.1	58.9	37.6	38.8	26.1	13.7	39.4	31.2
1970	39.2	61.0	39.9	40.2	27.7	14.0	36.9	32.3
1971	40.4	64.1	42.1	43.2	30.3	14.7	39.3	33.2
1972	42.1	67.7	44.7	46.6	32.5	15.6	41.2	34.8
1973	48.2	72.4	47.9	50.3	35.5	17.2	46.0	37.4
1974	55.1	77.4	54.5	55.1	41.1	20.5	56.7	41.5
1975	59.8	82.0	60.9	60.8	51.1	24.0	63.3	46.0
1976	61.6	85.6	66.8	66.3	59.6	28.0	69.2	49.4
1977	65.5	88.7	73.0	70.5	69.0	33.2	74.9	53.4
1978	72.0	91.1	79.7	73.4	74.7	37.2	78.1	58.2
1979	79.9	94.9	88.2	76.5	84.8	42.7	81.0	63.5
1980	86.8	100.0	100.0	81.5	100.0	51.8	87.2	69.9
1981	93.6	106.3	113.4	87.0	111.9	61.9	91.6	78.6
1982	97.4	111.9	126.8	92.1	121.5	72.1	94.1	87.1
1983	99.4	115.6	139.0	94.7	127.1	82.7	95.8	92.2
1984	103.2	118.4	149.3	97.8	133.5	91.6	98.0	96.2
1985	105.6	120.9	157.8	100.0	141.6	100.0	100.0	100.0
1986	108.5	120.8	161.8	100.1	146.4	105.9	100.6	104.2
1987	114.0	121.1	167.1	99.4	152.5	110.9	100.7	108.7
1988	118.2	122.6	171.7	100.1	160.0	116.5	101.4	113.1
1989	121.7	126.0	180.1	101.2	172.5	123.8	103.7	118.7
1990	131.7	129.4	184.8	103.7	188.9	131.7	106.9	124.4
1991	137.3	133.5	191.8	107.7	199.9	140.1	110.4	131.4

NOTES: Consumer price indices from IMF, *International Financial Statistics*.

C5.7: Real Exchange Rates for Germany, France, the Netherlands, Great Britain, Italy, Japan, and Canada, 1961–91

YEAR	rx_t^{DEU}	rx_t^{FRA}	rx_t^{NLD}	rx_t^{GBR}	rx_t^{ITA}	rx_t^{JPN}	rx_t^{CAN}
1961	2.539	5.458	4.105	4.410	1,886.6	427.5	1.237
1962	2.463	5.228	4.009	4.263	1,808.6	405.0	1.299
1963	2.430	5.051	3.943	4.248	1,728.3	380.8	1.313
1964	2.405	4.969	3.787	4.160	1,653.9	373.0	1.305
1965	2.381	4.937	3.646	4.061	1,622.2	356.7	1.304
1966	2.414	5.057	3.641	4.115	1,662.1	356.8	1.319
1967	2.397	4.966	3.530	3.998	1,654.4	345.8	1.285
1968	2.443	4.909	3.540	3.430	1,691.7	339.8	1.276
1969	2.484	5.125	3.465	3.411	1,738.3	339.0	1.286
1970	2.352	5.457	3.527	3.396	1,741.9	332.8	1.272
1971	2.200	5.319	3.268	3.246	1,631.4	313.6	1.229
1972	1.983	4.756	2.900	3.241	1,577.1	270.4	1.198
1973	1.779	4.486	2.679	3.329	1,700.6	228.9	1.289
1974	1.842	4.867	2.688	3.136	1,742.9	247.6	1.299
1975	1.794	4.209	2.487	2.600	1,701.2	244.5	1.322
1976	1.812	4.407	2.456	1.867	1,922.9	230.1	1.230
1977	1.715	4.409	2.280	1.657	1,718.5	204.7	1.304
1978	1.587	4.077	2.122	1.850	1,605.2	169.3	1.411
1979	1.543	3.854	2.095	1.999	1,503.7	188.7	1.474
1980	1.578	3.668	2.117	2.019	1,558.9	196.8	1.452
1981	1.990	4.486	2.684	1.696	1,814.2	196.8	1.428
1982	2.112	5.048	2.824	1.403	1,850.7	225.1	1.380
1983	2.195	5.450	2.996	1.186	1,995.6	214.8	1.329
1984	2.481	6.041	3.386	1.033	2,181.5	218.3	1.389
1985	2.571	6.012	3.507	0.967	1,772.5	219.8	1.442
1986	1.949	4.643	2.654	1.087	1,391.5	158.5	1.446
1987	1.692	4.100	2.324	1.225	1,202.3	142.9	1.391
1988	1.693	4.099	2.333	1.315	1,324.6	130.3	1.286
1989	1.848	4.447	2.596	1.178	1,271.5	143.9	1.236
1990	1.644	3.879	2.312	2.561	1,197.7	178.3	1.235
1991	1.707	4.040	2.384	2.577	1,215.8	167.5	1.197

NOTES: rx_t^j converts from constant-dollar prices to real units of currency j. It is the market exchange rate, units of j per dollar, times the U.S. CPI, divided by the country j CPI. For Great Britain, it is the inverse of this exchange rate. All data are from IMF, *International Financial Statistics*.

C5.8: Population of the United States, Germany France, the Netherlands, Great Britain, Italy, and Japan, 1961–91

$YEAR$	pop_t^{USA}	pop_t^{DEU}	pop_t^{FRA}	pop_t^{NLD}	pop_t^{GBR}	pop_t^{ITA}	pop_t^{JPN}
1961	183.69	56.18	46.16	11.64	52.81	49.90	94.95
1962	186.54	56.94	47.00	11.80	53.27	50.24	95.83
1963	189.24	57.59	47.82	11.97	53.54	51.18	96.81
1964	191.89	58.27	48.31	12.12	53.85	51.57	97.83
1965	194.30	59.01	48.76	12.29	54.18	51.99	98.88
1966	196.56	59.50	49.16	12.45	54.50	52.33	99.79
1967	198.71	59.87	49.55	12.60	54.80	52.67	100.83
1968	200.71	60.17	49.94	12.72	55.05	52.99	101.96
1969	202.68	60.44	50.32	12.87	55.27	53.32	103.17
1970	205.05	60.71	50.77	13.03	55.63	53.66	104.34
1971	207.66	61.29	51.25	13.19	55.91	54.01	105.70
1972	209.90	61.67	51.70	13.33	56.08	54.41	107.19
1973	211.91	61.97	52.13	13.44	56.21	54.80	108.71
1974	213.85	62.04	52.49	13.54	56.22	55.10	110.16
1975	215.97	61.83	52.79	13.65	56.21	55.40	111.57
1976	218.04	61.51	52.91	13.77	56.21	55.70	112.77
1977	220.24	61.40	53.15	13.85	56.18	55.93	113.86
1978	222.59	61.33	53.38	13.94	56.17	56.13	114.90
1979	225.06	61.44	53.61	14.03	56.23	56.29	115.87
1980	227.74	61.56	53.88	14.14	56.31	56.42	116.81
1981	230.04	61.67	54.18	14.25	56.35	56.50	117.66
1982	232.35	61.64	54.48	14.31	56.34	56.64	118.48
1983	234.55	61.42	54.73	14.36	56.38	56.84	119.31
1984	237.00	61.13	54.95	14.42	56.49	57.00	120.08
1985	239.28	60.97	55.17	14.48	56.62	57.13	120.84
1986	241.62	61.01	55.36	14.56	56.76	57.22	121.49
1987	243.94	61.08	55.63	14.66	56.93	57.35	122.09
1988	246.31	61.45	55.87	14.76	57.07	57.44	122.61
1989	248.76	62.06	56.16	14.83	57.24	57.52	123.12
1990	249.92	63.23	56.73	14.94	57.41	57.66	123.54
1991	252.69	64.12	57.05	15.06	57.37	57.05	123.92

NOTES: Data are in millions, from IMF, *International Financial Statistics*.

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