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Economic analysis of pesticide regulation in the U.S. apple industry

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Economic analysis of pesticide regulation in the U.S. apple industry

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For the Graduate College

To my grandmother Agnes

TABLE OF CONTENTS

CHAPTER 1. GENERAL INTRODUCTION

Introduction

The Food Quality Protection Act (FQPA) that was passed into law in 1996 has revived interest in issues of pesticide regulation. It mandates a different approach to the regulatory management of risks posed by pesticide use in that it requires a consistent assessment of risks from pesticides with a similar mode of toxic action and it explicitly requires the regulatory agency to address risks posed to infants and children. In particular, FQPA draws critical attention to the use and safety of organophosphates, a group of insecticides that are widely used in apple production.

This dissertation addresses issues in the economic analysis of pesticide regulation in apple production. The U.S. apple industry is a highly pesticide-intensive industry: 96% of the bearing apple acreage is treated with insecticides, 90% with fungicides, and 60% with herbicides. This amounts to 44 lb. of active ingredient applied per acre (U.S. Department of Agriculture).

Several particularities of apple production systems require a careful consideration of the methods that are used to estimate regulatory impacts. Growing conditions are very heterogeneous across the United States due to differences in climate and pest pressure and regional redistribution impacts need to be estimated. Quality aspects are important to recognize as growers receive considerable premia when producing fruit that qualifies for the high-value fresh market. In addition, dynamic analysis is required in production systems where trees once planted bear fruit for several years or even decades. Besides addressing these aspects that are specific to pesticide regulation in production systems of fruit and perennial crops, this dissertation proposes a method to acknowledge the uncertainty in ex-ante assessments of regulatory actions.

The study begins by formulating a partial-equilibrium model of the U.S. apple industry, where apple orchards are modeled as multiproduct firms producing apples for fresh and processed utilization. The model is structured to facilitate the estimation of disaggregated welfare impacts on consumers and different groups of producers in the two markets. An econometric model of U.S. apple supply and demand that incorporates net imports and that acknowledges the strong links between the markets for fresh and processed apples is estimated on a regional basis and elasticity estimates are obtained. Using expert opinion data on production impacts, the model is employed to estimate the economic effects of hypothetical bans on seven different fungicides and seven different herbicides.

The dissertation then turns to the issue of incorporating experts' uncertainty into ex-ante welfare assessments. Because of a lack of historical and experimental data, economic assessments of regulatory actions are frequently based on expert opinion. Although this is in many cases the best or only data available, experts themselves are often uncertain about possible impacts. Such uncertainty has nontrivial consequences for welfare analysis. A method based on Bayesian updating is proposed to combine dispersed expert opinion arising as a collection of probability estimates over a finite number of events. The methods are implemented using as an example a hypothetical ban on one organophosphate, azinphos-methyl, and the whole group of organophosphates in U.S. apple production. Production impact distributions are estimated and distributions of economic welfare changes are obtained for different policy scenarios. A nonparametric test is used to order the outcome distributions in their welfare properties.

The final part of this dissertation analyzes the question of how pesticide regulation impacts the long-term decision to replant an orchard. The topic is addressed under the particular consideration of antibiotic use in apple production. Antibiotics are used in fruit production to control fire blight, a bacterial disease of apple and pear trees that can considerably lower yields for several years and eventually lead to tree death. The use of antibiotic agents in agriculture is a subject of growing concern to scientists and public health officials because of fear of widespread resistance development that would make the use of antibiotics ineffective in human health care. Furthermore, resistance development in the fire blight bacteria itself threatens the availability of effective means for fire blight control.

Existing economic models of pesticide regulation do not consider such long-term impacts on the survival probability of a perennial crop. A Faustmann-type model of orchard replanting is proposed as a framework that can incorporate the changes in survival probability of an orchard. The optimal replanting time is derived and the replanting decision of a single grower is embedded in an industry equilibrium to facilitate a welfare analysis of changes in the production environment. The model is studied using analytical and numerical tools and estimates of welfare impacts are obtained for a hypothetical ban on antibiotics use in apple production.

Dissertation Organization

In addition to this introduction, the dissertation consists of three independent papers, and although the papers are thematically closely related, each is fully self-contained with an introduction stating and motivating the research question, a model section, and an empirical application. Given the wide spread of topics used in this research, an independent survey of the literature at the beginning of the dissertation seemed to be unsatisfactory. For this reason, the literature is reviewed in each paper as needed to put the work into context. The dissertation concludes with a general summary of the results.

References

U.S. Department of Agriculture. NASS/ERS. *Agricultural Chemical Usage: Fruits Summary*. Washington, DC, 1998.

CHAPTER 2. ECONOMIC ASSESSMENT OF CHEMICAL USE RESTRICTIONS IN U.S. APPLE PRODUCTION

A paper to be published as part of the report
"Benefits of Pesticide Use in Apple Production"
A special funded project of the U.S. Department of Agriculture National Pesticide Impact Assessment Program [1]

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Abstract

A partial-equilibrium model of U.S. apple supply and demand is developed in order to estimate the welfare impacts of pesticide use cancellations. Apple orchards are described as multiproduct firms, producing apples for fresh and processed utilization. This setting allows us to acknowledge the market links that exist between the market for fresh and processed apples and to incorporate quality impacts of the regulation into the assessment. Welfare impacts for seven fungicides and seven herbicides are assessed. The most important impacts are implied by a cancellation of the herbicides glyphosate ($9.6 mill.) and simazine ($8.0 mill.) and the fungicides Egosterol-Biosynthesis Inhibitors ($5.8 mill.), captan ($2.6 mill.), and mancozeb ($1.6 mill.).

Introduction

The U.S. apple industry is a highly pesticide-intensive industry. In 1995, the USDA NASS/ERS Agricultural Chemical Usage: Fruit Summary estimated that 114 different active ingredients of pesticides or growth regulators were applied in apple production.[4] Overall, 98% of the bearing apple acreage is treated with insecticides, 93% with fungicides, and 63% with herbicides. This amounts to 46 lb. of active ingredient (a.i.) applied per acre.

The industry has a $1.7 bill. annual value of production at the farm level (1996). The major apple producing state is Washington where about 50% of the 10 bill. lb. national crop and 66% of U.S. fresh apples are produced (data are 1994-96 averages). Other major apple producing states are New York (1,080 mill. lb. total production, of which 45% are consumed fresh), Michigan (990 mill. lb., of which 32% are consumed fresh), California (930 mill. lb., of which 35% are consumed fresh), Pennsylvania (430 mill. lb., of which 31% are consumed fresh), Virginia (320 mill. lb., of which 31% are consumed fresh), North Carolina (240 mill. lb., of which 30% are consumed fresh), and Oregon (160 mill. lb., of which 74% are consumed fresh).

Production conditions for apples are very heterogeneous across the United States and, due to climatic differences, production systems vary widely. This is particularly true with respect to disease pressure where western production regions benefit from their arid climate. These disparate pest pressure situations become apparent in the study of cost of production estimates. While insect management costs are relatively invariant at about $180/acre across the United States, disease control cost (mainly fungal) vary widely from $130/acre in the western states through to $260/acre in the central states and to $320/acres in the eastern states (Clark and Burkhart; Funt et al.; Hinman et al.; Kelsey and Schwallier; Parker et al.; Pennsylvania Agricultural Extension Service; Vossen et al.).[5] These large differences in costs of disease control suggest that pesticide regulation will have strong distribution impacts for apple producers in the different production regions and that this will in particular be true for fungicides.

O'Rourke states that "Government intervention [in the apple industry] has tended to be most intrusive in the control of chemical use by orchardists." (p. 177) The Food Quality Protection Act (FQPA) that passed into law in 1996 has brought new attention to issues of pesticide regulation, because it mandates a different approach to the regulatory management of risks posed by pesticide use. It requires a consistent assessment of risks from pesticides with a similar mode of toxic action and it is expected that in particular the availability of insecticides and fungicides will be affected once they have been reviewed under the new statute. Despite the fact that the FQPA requires a risk assessment for classes of pesticides instead of for single pesticides, an economic assessment of the value of single pesticides is still needed in order to make economically sound decisions when deciding which pesticide uses to keep and which to cancel. The use of such information enables the regulatory agency to achieve a desirable risk reduction while minimizing the regulatory costs.

The goal of this paper is to estimate the production and welfare distribution impacts of pesticide regulation at a regionally disaggregated level. To this end, a regional econometric model of apple supply and demand is estimated and applied to the ex-ante estimation of welfare changes caused by pesticide regulation. Scenarios are based on hypothetical bans of single pesticides where production impact estimates are obtained from an expert opinion study. The assessment is conducted for the seven fungicides and the seven herbicides that are considered being the most important ones in apple production.

The paper continues with a description of the economic model of a pesticide ban. Starting from a partial-market equilibrium model, changes in supply and demand in different market segments are derived. Issues of welfare analysis in horizontally related markets are addressed and the interaction of supply shifts between the market segments is illustrated in a diagrammatic exposition. We discuss the data that enter the ex-ante estimation of welfare changes due to pesticide bans and explain the computational techniques employed. The section is accompanied by a discussion of preliminary simulations that aid us in understanding the model behavior. We report results on estimated welfare changes due to pesticide cancellations, focusing on the regional distribution effects and the reallocation effects between the markets for apples allocated to fresh and processed utilization. The paper concludes with a summary of the findings.

Economic Model of a Pesticide Ban in Apple Production

In apple production pesticides are mainly used to preserve quality and protection against yield losses is generally a secondary consideration. We model apple production orchards as joint-product firms producing apples for the fresh and processing market. The fresh market pays a considerable premium and a deterioration of quality is modeled as a decrease in the share of fruit allocated to the fresh market. The marginal welfare analysis suggested by Lichtenberg, Parker, and Zilberman is extended to this multiproduct analysis. In this framework, supply and/or demand functions are assumed to undergo parallel shifts given changes of the production technology, and flexibility estimates are used to calculate price and quantity changes.

The model is one of partial equilibrium, and growers are arranged into $j=1,\ldots, J$ groups according to how their marginal-cost function is impacted by the loss of a pesticide. The cancellation of a pesticide presents a change in the technology available to growers, and the shift in technology is parameterized by λ. If growers do not use the pesticide, their technology is independent of λ.

Specifically, producers are grouped into sets of users and non-users of a pesticide in different geographical production regions: West, Midwest, Northeast, Mid-Atlantic, and Southeast. We order the groups such that j=1,..., k identify the producers who are affected by a change in λ, i.e. in our case the users of a pesticide to be banned, and j=k+1,..., J, denote the producers groups that are not affected by a ban. Denoting prices by P and quantities by Q, with subscript j identifying regions and superscript F and P signifying fresh and processed, respectively, the partial equilibrium can be described as:

Supply User:	$P_j^i = MC_j^i(Q_j^F, Q_j^P, \lambda)$,	$i = F, P; j = 1,...,k$	(1.1)
Supply Non-User:	$P_j^i = MC_j^i(Q_j^F, Q_j^P)$,	$i = F, P; j = k+1,...,J$	(1.2)
Regional Pricing:	$P_j^i = h_j^i(P^i)$,	$i = F, P; j = 1,...,J$	(1.3)
Demand:	$D^i(Q_d^i) = P^i$,	$i = F, P$	(1.4)
Net Imports:	$Q_M^i = M^i(P^i, \sum_j Q_j^i)$,	$i = F, P$	(1.5)
Market Clearing:	$\sum_{j=1}^J Q_j^i + Q_M^i = Q_d^i$,	$i = F, P$	(1.6)

Equation (1.1) is the supply function for pesticide users and equation (1.2) is the supply function for non-users. The marginal-cost functions (MC) depend on production to the fresh and processing sector to capture the joint-product character of the technology. Users and non-users produce at a level such that their marginal costs equals price both in the fresh and processing market. Equation (1.4) presents the inverse demand function (D) for fresh or processing apples. Demand is modeled at the U.S. level and P^i is the U.S. level price and depends on the quantity consumed, Q_d^i. The regional supply functions are linked to the U.S.

demand via regional pricing equations presented by $h^i_j(P^i)$ in equation (1.3). Equation (1.5) models net imports (Q^i_M) and the last equation (1.6) poses the market clearing conditions.

Totally differentiating this system, one can derive the equilibrium impacts of a change in technology (the loss of a pesticide) which is parameterized as a shift in λ.

$$f_j^{FF}\frac{P_j^F}{Q_j^F}dQ_j^F + f_j^{FP}\frac{P_j^F}{Q_j^P}dQ_j^P - dP_j^F = -\frac{\partial MC_j^F}{\partial\lambda}d\lambda \qquad j=1,\dots,k \quad (2.1a)$$

$$f_j^{PF}\frac{P_j^P}{Q_j^F}dQ_j^F + f_j^{PP}\frac{P_j^P}{Q_j^P}dQ_j^P - dP_j^P = -\frac{\partial MC_j^P}{\partial\lambda}d\lambda \qquad j=1,\dots,k \quad (2.1b)$$

$$f_j^{FF}\frac{P_j^F}{Q_j^F}dQ_j^F + f_j^{FP}\frac{P_j^F}{Q_j^P}dQ_j^P - dP_j^F = 0 \qquad j=k+1,\dots,J \quad (2.2a)$$

$$f_j^{PF}\frac{P_j^P}{Q_j^F}dQ_j^F + f_j^{PP}\frac{P_j^P}{Q_j^P}dQ_j^P - dP_j^P = 0 \qquad j=k+1,\dots,J \quad (2.2b)$$

$$dP_j^i - \frac{\partial h_j^i}{\partial P^i}dP^i = 0 \qquad i=F,P;\ j=1,\dots,J \quad (2.3)$$

$$f_d^{ii}\frac{P^i}{Q_d^i}dQ_d^i - dP^i = 0 \qquad i=F,P \quad (2.4)$$

$$dQ_M^i - e_{MP}^i\frac{Q_M^i}{P^i}dP^i - e_{MQ}^i\frac{Q_M^i}{\left(\sum_j Q_j^i\right)}d\left(\sum_{j=1}^{J}Q_j^i\right) = 0 \qquad i=F,P \quad (2.5)$$

$$dQ_1^i + \cdots + dQ_J^i + dQ_M^i - dQ_d^i = 0 \qquad i=F,P \quad (2.6)$$

Expression f_j^{KL} denotes the flexibility of the price of good K with respect to the quantity of good L, where j indexes the region. The flexibility is a demand flexibility if $j=d$. For net imports e_{MP}^i and e_{MQ}^i indicate the elasticities of net imports with respect to U.S. price level and U.S. production for the respective market *i*. System (2) is linear in the endogenous quantity and price changes and, given the exogenous shocks to the marginal-cost functions, can be solved by inversion. It is equivalent to system (2) in Lichtenberg, Parker, and

Zilberman, but for the cross-price flexibilities that are included here to model value losses arising from reallocation of fruit from the fresh to the processing market.[6]

Welfare Analysis

Using the solutions for changes in quantities and prices according to system (2), consumer and producer surpluses can be calculated assuming, as in Lichtenberg, Parker, and Zilberman, that shifts in supply curves are linear. This assumption is suitable if shifts are small which is an adequate assumption for our case, because we consider only single pesticide use restrictions in this study. In most cases, orchard managers can replace the lost pesticide by more or less suitable substitutes and impacts on cost of production, yield, and quality are small.

To derive the welfare implications for producers we start from the profit maximization problem of the grower who chooses the optimal quantities Q_j^F and Q_j^P according to

$$\max_{Q_j^F, Q_j^P} \pi_j = P_j^F Q_j^F + P_j^P Q_j^P - C(Q_j^F, Q_j^P; \lambda) \tag{3}$$

The first-order conditions define the market supply functions and can be stated according to (1.1) or (1.2) for users and non-users of the pesticide, respectively. The profit-maximizing solutions of Q_j^F and Q_j^P are denoted as $\hat{Q}_j^F$ and $\hat{Q}_j^P$. Abstracting from fixed costs, producer surplus is defined as $R_j = P_j^F Q_j^F + P_j^P Q_j^P - C(Q_j^F, Q_j^P; \lambda)$. Assuming that output *i* is a necessary output, the change in producer surplus for the non-users of a pesticide is defined as

$$\Delta R_j = \int_{P_{0_j}^i}^{P_{1_j}^i} \left\{ \hat{Q}_j^i + \left[P_j^i - MC_j^i(\cdot)\right] \frac{\partial Q_j^i}{\partial P_j^i} + \left[P_j^{-i} - MC_j^{-i}(\cdot)\right] \frac{\partial Q_j^i}{\partial Q_j^{-i}} \frac{\partial Q_j^{-i}}{\partial P_j^i} \right\} dP_j^i$$

where P_{0j}^i denotes the original price level and P_{1j}^i signifies the price level after the change in λ. Here, the superscript i can here denote either F or P, implying that $-i$ indicates the other. Employing the envelope theorem, the last two terms of the integrand sum to zero and

$$\Delta R_j = \int_{P_{0j}^i}^{P_{1j}^i} \hat{Q}_j^i \, dP_j^i \qquad j = k+1,\ldots,J. \qquad (4)$$

The equilibrium supply $\hat{Q}_j^i$ responds thereby to price changes in both markets, i.e. P_j^{-i} is not held fixed. Welfare impacts in horizontally related markets can thus be assessed using the equilibrium supply curve in any of the affected market (Just, Hueth, and Schmitz, pp. 337-48).

For the users of the pesticide, the change in producer surplus can be derived as the analogue to (4), but it now acknowledges the shift in the cost function due to the change in λ

$$\Delta R_j = \int_{P_{0j}^i}^{P_{1j}^i} \hat{Q}_j^i \, dP_j^i - \int_0^{P_{1j}^F} \frac{dMC_j^F(Q_{1j}^F, Q_{1j}^P; \lambda)}{d\lambda} dP_j^F - \int_0^{P_{1j}^P} \frac{dMC_j^P(Q_{1j}^F, Q_{1j}^P; \lambda)}{d\lambda} dP_j^P \qquad (5)$$

for $j = 1,\ldots,k$.

Equivalent to (4) and (5), the changes in producer surplus can be calculated in each market separately employing the partial-equilibrium supply curves $Q_j^i(P_j^i; Q_j^{-i})$, $i = F, P$. Using the latter approach changes in both markets have to be considered, because the surplus changes in one market are not calculated in the other. Since reallocation of production and surplus between the markets is an important aspect of this study, the latter approach was chosen.[7]

In this analysis, changes in demand result exclusively from changes in prices, and we ignore any possible changes in consumers' preferences for apples that could result from a change in the production method. Therefore the demand functions do not shift and the change in consumer surplus can be described by the difference in the consumer surplus before and after a change in pesticide availability and is calculated as $-dP^i(Q_d^i + dQ_d^i/2)$ in each market.

Calculating Marginal-Cost Changes

To solve (2), an estimate of the marginal-cost change for producer group j is needed. A grower chooses the profit-maximizing level of production for the fresh and processed market using her technology described by the cost function $C_j(Q_j^F, Q_j^P; \lambda)$. According to the profit-maximization problem (3), she will choose the level of production that equates the marginal cost of producing for the fresh and processed market with the respective price, as described in (1.1) and (1.2). The problem is isomorphic to selecting the optimal level of yield, Y_j, and the optimal share of fruit going to the fresh market, α_j, according to

$$\max_{\alpha_j, Y_j} \; \pi_j(Y_j, \alpha_j; \lambda) = \left(\alpha_j P_j^F + (1-\alpha_j)P_j^P\right)Y_j - \Psi_j(Y_j, \alpha_j; \lambda)$$

where $\Psi_j(\cdot)$ is the alternative cost function specification that arises from the same technology as $C_j(Q_j^F, Q_j^P; \lambda)$. It is assumed to be convex in Y_j and α_j. The first-order conditions can be stated as

$$\begin{aligned} \Psi_{j,Y}(Y_j, \alpha_j, \lambda) &= \alpha_j P_j^F + (1-\alpha_j)P_j^P \\ \Psi_{j,\alpha}(Y_j, \alpha_j, \lambda) &= (P_j^F - P_j^P)\,Y_j \end{aligned}$$

where second subscripts on Ψ_j denote first derivatives. This system of equations can be solved for

$$P_j^F = MC_j^F(Q_j^P, Q_j^P, \lambda) = \Psi_{j.Y} + (1-\alpha_j)\,\Psi_{j.\alpha} / Y_j$$
$$P_j^P = MC_j^P(Q_j^P, Q_j^P, \lambda) = \Psi_{j.Y} - \alpha_j \Psi_{j.\alpha} / Y_j$$

Following Lichtenberg, Parker, and Zilberman, we approximate locally marginal costs of yield and fresh share by their average costs, i.e., $\Psi_{j.Y} = W_j / Y_j$ and $\Psi_{j.\alpha} / Y_j = P_j^F - P_j^P$, where the parameter W_j denotes the per acre cost of production. Then totally differentiating the marginal-cost functions with respect to changes in cost of production, W_j, yield, Y_j, and fresh share, α_j, the change in marginal costs of fresh and processing production in the j-th region are derived as

$$\left[dW_j / Y_j - (\alpha_j P_j^F + (1-\alpha_j) P_j^P)\, dY_j / Y_j \; - \; (P_j^F - P_j^P)\; d\alpha_j\right] \Big/ \left(1 + 0.5\; dY_j / Y_j\right) \quad (6)$$

A cautionary remark on equation (6) is in place. The loss of a particular pesticide might have other negative impacts on orchard management that are not easily captured as changes in cost of production, yield, or quality. Apple production systems and pest systems are very complex and changes in pesticide availability can lead to changes in the overall system performance, even if direct effects on yield or fresh market allocation might be negligible. Because of such effects growers might decide to use one pesticide over another despite the fact that marginal cost of production according to (6) increases. Hubbel and Carlson have shown that this can be the case with regard to insecticide choices where apple producers incorporate variables such as worker safety or environmental soundness into their insecticide choice.

A Diagrammatic Exposition

The effect of a pesticide ban on the interlinked markets for fresh and processed apples is somewhat involved and we illustrate the working of system (2) in a set of diagrams. We start with figure 1, where we first assume that the markets for fresh and processed apples can be analyzed separately. This strong assumption is relaxed in the discussion of figure 2, where the interrelationships between the markets are included in the manner modeled in the analytical and empirical analysis. This stepwise procedure helps to clarify the concepts of our analysis, and to distinguish between different forces that will jointly determine the final welfare impact of a pesticide use restriction.

The upper three diagrams in figure 1 show a model of the market for fresh apples and the lower three diagrams show the same for processed apples. The leftmost diagrams depict the market equilibrium; S^0 is the original (before regulation) supply curve, and D the demand curve for the fresh market (1A) and processing market (1D), respectively. The prevailing market price is PF^0 (PP^0). In figures 1B (1E) and 1C (1F), the market supply function is split into the supply for the users of the pesticide (center diagrams) and non-users (right diagrams). For both, users and non-users, the market price PF^0 (PP^0) will be the relevant price at which their product is sold.

A technology shift due to a pesticide ban is represented by an upward shift of the supply curves for the users of the pesticide. At the same time, the supply function for non-users remains unchanged. Summing horizontally, total market supply for fresh (processed) apples will shift upwards, from S^0 to S^1 in diagram 1A (1D).

At the new market price PF^1 (PP^1), previous users will supply fewer apples given their new supply function S^1 (1B, 1E), and non-users supply more (1C, 1F), because they receive a higher price while their technology is unaffected. In our graphs, non-users clearly benefit from an increase in the market price, a result that holds true as long as we ignore the interdependence of the supply functions for fresh and processed apples. The total quantity of fresh and processed apples supplied decreases (left pointing arrow on the QF-axis (QP-axis)).

Introducing the dependence between the markets of fresh and processing apples, the supply functions in the fresh market shift in response to changes in the market for processed apples and vice versa. From elasticity estimates obtained from an econometric model that is presented in appendix 2A, we know that the production of fresh apples decreases in the price of processed apples and the production of processing increases in the price of fresh apples. In figure 1, we saw that the pure technological effect of a pesticide-use restriction results in an increase of prices ($PF^1>PF^0$ and $PP^1>PP^0$). Therefore, the supply functions of fresh apples from users and non-users shift upward, whereas the supply functions of processed apples from users and non-user shift downwards. The new supply functions are denoted by superscript "2" and the new prevailing market prices are denoted by PF^2 and PP^2 (figure 2).

We turn now to the welfare assessment of the changes in the market for fresh and processed apples and as explained in the previous section, we employ the partial-equilibrium supply curves. Evaluating the overall impact and acknowledging the changes in the market environment, we compare situation "0", the market equilibrium before change, to situation "2", the new market equilibrium. The change in producer surplus is defined as the difference in the areas behind the supply curves as illustrated in figure 3. Figure 4 illustrates the concept of a change in consumer surplus.

In this assessment we will not only divide producers into users and non-users, but also distinguish users and non-users by region. The diagrammatic analysis would have to be extended to model additional producer groups, but the general procedure would remain the same.

Data

Apple production systems differ widely across production areas, and for this reason we assess impacts of pesticide regulation by region. We distinguish five major apple-producing regions: West, Midwest, Northeast, Mid-Atlantic, and Southeast. The states composing each region are listed in table 1 together with production and revenue data for each region. The West is the most important production region and receives annual revenue of $1.1 bill. from apple production. Midwest, Northeast, and Mid-Atlantic are relatively similar in their importance, each with annual revenue of about $150 mill., and the Southeast is the smallest production region with $39 mill. revenue coming from apple production. Figure 5 maps the five regions and the bars indicate the revenue from apple production in the respective states.[8]

Change in Cost of Production, Yield, and Quality

The biological sections of the project report to the USDA-NAPIAP assessment of pesticide use in apple production present data obtained in expert opinion surveys. It includes data on current pesticide use patterns and on pesticide use scenarios in the case of single pesticide cancellations. In detail, estimates of the acreage that is currently treated by a pesticide and the current use rates are given for the states listed in table 1. For the cancellation scenarios, they estimate the proportion of currently treated acreage on which the canceled pesticide would be replaced by each alternative, the use rates of each substitute pesticide, and how yield and production share allocated to fresh consumption would be affected by such a replacement. Estimates are given for the year following a hypothetical pesticide ban.[9]

These data allow us to calculate changes in the cost of production using a partial-budgeting approach. Pesticide prices are taken from USDA NASS agricultural prices statistics (1996 for herbicides, 1997 for fungicides). If a price for a particular pesticide is not published, chemical suppliers in different geographical regions were contacted by phone and asked for the price at which the product would typically be sold to apple orchards. Averages were formed for our analysis. We crosschecked prices published by USDA/NASS with prices elicited from chemical suppliers and found only minor differences.

The application costs are estimated using updated estimates from enterprise budgets (Clark and Burkhart; Funt et al.; Hinman et al.; Kelsey and Schwallier; Parker et al.; Pennsylvania Agricultural Extension Service; Vossen et al.) and cost of applying herbicides/fungicides is appraised at $6.40/$10.84 per acre. Mowing is an often suggested replacement strategy for the application of herbicides and its cost is estimated at $11.83/acre.

Using the estimates for cost of production, yield, and quality changes, marginal-cost changes are estimated via equation (6). In some instances the marginal costs are lower under the replacement scenarios than under current use patterns and this poses a problem for our analysis. Such results can occur when growers choose a pesticide for indirect benefits that are not acknowledged in (6). In these cases, the change in marginal cost is set to zero. We motivate this by the assumption that the nonquantifiable benefits, on e.g. worker safety, integrated pest management (IPM) programs, or resistance management, are at least as large as the extra cost of using the currently used pesticide.[10]

Elasticity Estimates and Market Data

Regional supply elasticities are estimated together with demand elasticities and import responses in an econometric modeling effort that is presented in appendix 2A. The model arranges U.S. apple production into four apple-producing regions, Northwest, Southwest, Midwest, and East, for each of which a production and allocation component is estimated. The demand component of the model describes demand for fresh and processed apples at the U.S. level, and regional price levels are allowed to differ by linking the demand and the supply components via regional pricing equations. Short-run (year 1) and long-run (year 5) elasticities are numerically estimated by shocking the model at the means of the data. Because experts report production technology changes for the year after a hypothetical pesticide ban and because the project requires us to estimate first-year impacts, short-run elasticities are inverted to yield flexibility estimates that are used in the estimation of market impacts.[11]

Data on current prices and quantities were obtained from USDA publications, and market quantities and prices for fresh and processed apples were calculated using an average of 1994-96 data. They are listed in table 1. A three-year average was used because prices and quantities in the apples market can be quite volatile depending on weather, pest, and (foreign) market conditions. By averaging prices and quantities we obtain impact estimates for an "average year".

Computational Issues

Changes in quantities and prices are calculated by inversion of system (2), while employing the flexibility estimates from the appendix. The regional units of analysis when employing system (2) are the states listed in table 1.[12,13] For the result section, impacts by states are then summed within a region to yield regional impacts.

Preliminary Simulation

States are treated very heterogeneously because they differ in marginal costs and prices according to market data. Furthermore, transfers of price shocks and supply response elasticities vary by region. We conduct a preliminary simulation to improve our understanding of the model and we shock the marginal-cost function by 1 ¢/lb. on 50% of the acreage in all regions. The changes in economic surplus for producers and consumers are shown in table 2. The first column shows the sum of impacts in the markets for fresh and processed apples. The changes in the market for fresh apples are listed in columns 2-5 of the table and columns 6-9 described the changes in the market for processed apples.

The shift in the marginal-cost function reduces supply, and quantities sold decrease and prices increase in both markets. Consequently non-users benefit, while users and consumers suffer losses in economic surplus. The change in net imports caused by the changes in production and prices can be read as the difference in quantity produced and quantity consumed. In table 2, net imports increase by 5.1 mill. lb. in the fresh market and by 12.2 mill. lb. in the processed market.

In appendix 2A, elasticity estimates show that the demand for fresh apples is less elastic than the one for processed apples, and that imports respond more elastically to quantity and price changes in the processed market than they do in the fresh market. Accordingly consumers bear a larger part of marginal-cost increases in the fresh market than in the market for processed apples. Specifically, in the fresh market consumer bear 97% of the $4.7 mill. total economic surplus loss, while in the processed market, producers bear the larger share of 68% of the $2.8 mill. loss. In terms of producer surplus, price increases almost compensate for cost increases and supply reductions shock in the fresh market, because the demand is sufficiently inelastic (Babcock; Lave).

Turning to the regional distribution of producer impacts, we see that of all regions the West experiences the largest loss. Given that the West also produces by far the largest share of total supply, it is instructive to analyze the losses relative to the annual revenue in the region. In relative terms, the Northeast loses the most and the first-year loss amounts to 0.2% of annual revenue. For the Southeast, Mid-Atlantic, West, and Midwest the drop has a size of 0.16%, 0.14%, 0.13%, and 0.02%. Users lose overall $3.3 mill. and non-users gain $1.8 mill. in surplus. In general, the relative size of economic surplus losses appears small; however, they compare to results that Lichtenberg, Parker, and Zilberman found for similar scenarios in plum, almond, and prune production.

Because of the long-time horizon of investments into apple production, we repeat the estimation using the long-term (year 5) flexibilities. In year 5, the annual surplus impact will be much stronger and total losses amount to $62.2 mill. (table 3). Losses increase because we acknowledge now also adjustments in long-term investments in addition to adjustments in variable inputs.

Fungicide Analysis

We begin our policy study with the analysis of fungicide cancellations. Fungicides are used to manage a very complex system of diseases and the implications of fungicide regulation are complicated by two factors. On the one hand, a fungicide can be used to combat several diseases at the same time. But on the other hand, fungicides are often applied in combination to increase their efficacy in combating one disease or several diseases.

The application of fungicides occurs during two principal growth periods, one being the early part of the season during bloom and fruit setting and the other being the summer. It is often thought that a larger share of consumer risks from pesticide exposure stems from pesticide use close to harvest time, and therefore it is sometimes considered to cancel pesticide use only during this season in order to limit the economic cost of the regulation. This motivated us to estimate the cost of elongating the preharvest interval by canceling the use of specific fungicides during the summer. In addition, we estimate the welfare impacts of banning the fungicide for the entire season.

We analyze removal scenarios for seven fungicides: Captan, mancozeb, dodine, ziram, benomyl, egosterol-biosynthesis inhibitors (EBI), and thiophanate-methyl. Rosenberger collects and summarizes expert opinion data on current fungicide use patterns and replacement scenarios. Information about the treated acreage and the proportion of fungicide use in the early season is given in table 4 together with expert estimates of cost, yield, and quality changes given a cancellation of summer use or a cancellation for the entire season.[14] Asterisks mark occasions in which the change in marginal cost is set to zeros because the marginal cost of the replacement technology is lower than that of the currently used technology.

Captan

Captan is a contact fungicide that is widely used to control many diseases especially in the central and eastern United States. It is a multi-site inhibitor of most fungi, and therefore no apple diseases have developed resistance to this fungicide. Growers dislike using it during the summer because it has a four-day reentry period which limits the time available for pruning and other orchard tasks. In many states, it is therefore mostly used in the early season. Often suggested alternatives are thiram, ziram, mancozeb, and EBI fungicides.

Because of a large increase in the number of applications, the replacement technology would be very expensive in Michigan and sizable quantity impacts are in addition expected in the southeastern states. Most of the losses would therefore accrue in the Midwest and Southeast (table 5). Captan is not widely applied in the western states and no cost impacts are expected. Western growers would therefore benefit from a use restriction and from the reduced supply of apples in the U.S. market. Overall, producers will gain in terms of producer surplus, but consumers suffer a surplus loss of $2.2 mill. if captan is canceled during the summer. When captan is banned for the whole season, welfare losses increase only slightly (table 6), mostly for growers in the Northeast and consumers. Total surplus losses amount to $2.6 mill.

Mancozeb

Mancozeb like captan is a contact fungicide. Ziram, captan, and EBI are often mentioned substitutes. Since mancozeb is used almost exclusively in the early season with the exception of the Southeast, a ban on mancozeb during the summer would have only small impacts (table 7). Because of relatively large marginal-cost impacts in the Northeast and Mid-Atlantic, growers in this region would be most impacted.

The situation is different for an outright ban on mancozeb (table 8). For Michigan replacement cost would be particularly high, allocation to fresh market decreases by 9.2% and yield decreases by 2.3%. Because of this, losses arise in the Midwest although it experiences a slight welfare gain if mancozeb is banned for summer use only. Growers in the Northeast would also incur largely increased losses. Total losses amount to $1.6 mill.

Dodine

Dodine is no longer widely used because resistance has developed in many eastern states. A loss of dodine for summer sprays would have small impacts in terms of welfare changes (table 9). In the scenario of banning dodine for the entire season most losses are incurred in the West (table 10), where larger cost of production impacts are expected together with decreases in quality. Overall impacts remain at $360,400 relatively small.

Ziram

Ziram is a summer fungicide that is commonly used in arid regions and often suggested alternatives are captan and mancozeb. Marginal costs increase only little and so producer surplus losses by users are relatively small as are quantity impacts (tables 11 and 12). Consumers are only slightly affected and total losses amount to $603,400 if ziram use is canceled during the entire growing season.

Benomyl

Benomyl is a broad-spectrum pesticide that is mostly used east of the Mississippi. A large share of its use occurs during the summer, but it has lost much of its initial effectiveness due to resistance development. The largest impacts due to a cancellation of benomyl use are expected in New York and Virginia/West Virginia and so most of the economic surplus losses occur in the Northeast and Mid-Atlantic (table 13). A complete ban on benomyl has negligible additional impacts in comparison to a ban on summer use only (table 14).

Egosterol-Biosynthesis Inhibitors (EBI)

EBI fungicides are a group comprised of fenamirol, myclobutanil, and triflumazole. They are important management tools against scab, rust, and mildew. With scab being the economically most important disease in the East and mildew being the economically most important disease in the West, EBI are important for disease control in all regions. All fungicides within this group have a very similar mode of action and are usually used in tank mixes with a contact fungicide such as captan or mancozeb to control resistance development and to increase the effectiveness of the treatment. Often suggested alternatives for the scenario of a ban on EBI are increased use rates and increased numbers of application for these contact fungicides.

EBI are mostly used during the early season and hence losses due to banning EBI use in the summer are small compared to an outright ban. Total losses would in this case amount to $1.7 mill (table 15) of which $1.1 mill. are losses in consumer surplus. Most of the decrease in surplus on the producer side would occur in the West, where a loss of these fungicides would result in significant cost increases, yield losses, and quality impacts.

Because of the availability of effective alternatives in the Southeast, the Midwest, and Mid-Atlantic, producers here would gain form price changes caused by decreased supply from western states.

The situation is different in the case of a ban on EBI for the whole season. Losses increase significantly and producers in the West, Mid-Atlantic, and Northeast would suffer negative impacts (table 16). Total losses would amount to $5.8 mill. and most the producer losses are incurred in the West ($740,300) and Midwest ($261,000). The Northeast would also suffer considerable losses of $160,000.

Thiophanate-Methyl

Thiophanate-Methyl is a fungicide similar to benomyl with slightly less activity against some summer diseases. It is not used in the western states, and in the other regions it is mostly used in the summer. A loss of thiophanate-methyl would have relatively limited cost of production impacts, no yield impacts, and few quality impacts.

Most losses after a ban on summer use of Thiophanate-Methyl would occur in the Northeast and Mid-Atlantic (table 17) where it is most widely used, and an outright ban on Thiophanate-Methyl substantially worsens impacts in the Northeast because of additional cost and quality impacts (table 18). Since the fungicide is not used in the West, growers there would benefit from the price increases due to the reduced supply from other regions.

Herbicides Analysis

In the economic analysis of hypothetical herbicide cancellations, we assess the cancellation impacts for seven herbicides: 2,4-D, diuron, glyphosate, norflurazon, oryzalin, paraquat, and simazine. Derr collects and summarizes expert opinion data on current use patterns and replacement scenarios. In many instances, herbicides are critical in the management of non-bearing orchards where they are used to control weed competition with young apple trees. Another important role of herbicide use is the control of weed blooms during apple pollination, so that fruit trees do not compete for bees with other flowering plants. Despite the fact that this competition for bees is very important, only a few studies have attempted to quantify the impact (one is Southwick and Southwick) and those impacts are largely ignored in the data that has been provided to us. Impacts on non-bearing acreage are also mostly ignored in this analysis. For this reason, our analysis will likely underestimate the economic impact of herbicide cancellations.

Studying table 19 which, similar to table 4, reports cost, yield, and quality impacts for herbicide cancellations reveals that in some states, acreage is treated by herbicides at a higher cost than their replacement chemicals, although the replacement would not lead to a reduction in yield or quality. This is the case because not all pesticide characteristics can be captured in terms of our marginal-cost function specification as it ignores aspects such as bee safety or impacts on IPM programs. Again we use the rule to set marginal-cost changes equal to zero in those instances and mark those cases by asterisks.

2,4-D

2,4-D is a herbicide used for post-emergence control of broadleaf weeds. There is currently no alternative available and this has implications especially for the control of dandelions during tree bloom. Still, impacts of a 2,4-D loss are relatively small and the welfare costs are estimated at $138,200 (table 20). Most of the losses are incurred by growers in the West.

Diuron

Diuron is a preemergence herbicide that is used for control of broadleaf weeds, and the most important alternative is simazine. The largely increased use of simazine predicted for the scenario of a ban on diuron would prompt an accelerated development of resistance to simazine.

A loss of diuron would increase costs of production in all regions and a significant yield loss is expected in North Carolina. Because of these heterogeneous impacts, growers in all regions but the Southeast and Mid-Atlantic would gain, and users in the Midwest would be compensated by price increases in the fresh market (table 21). Overall, quantifiable losses are at $284,200 relatively small, but it has to be kept in mind that these do not include possible long-term costs of increased resistance development.

Glyphosate

Glyphosate is used for the control of annuals and perennials, and in the West and Southeast it is applied to a large share of the acreage. Most alternatives are less effective, and the often-suggested alternative paraquat is problematic from a worker-safety perspective because of its higher acute toxicity. A loss of glyphosate would cause significant quality impacts in the Pacific Northwest and would lower yields in California, Pennsylvania, and North Carolina.

Hence the western states suffer substantial losses of $4.5 mill., most of which occur in the market for processed apples (table 22). Impacts in other regions are compensated for by changes in the market environment, i.e. by price increases. Consumers would suffer large losses especially in the fresh market. Total losses amount to $9.6 mill.

Norflurazon

Norflurazon is most important for weed control in non-bearing orchards. Replacement costs are often lower than current treatment costs and there are no yield and quality changes expected if norflurazon is banned. As a result no marginal-cost impacts are expected for most regions and the estimate of economic surplus losses is relatively meaningless because most benefits of norflurazon that accrue in non-bearing orchards are not quantified. For the quantifiable losses, the West is the only region that is notably affected with a $43,700 reduction of producer surplus (table 23).

Oryzalin

Oryzalin is a preemergence herbicide used to control annual grasses and small seeded broadleaf weeds. Its loss would be felt severely in weed control programs of non-bearing orchards. Although some alternative herbicides exist, they are not labeled for use in non-bearing orchards. Oryzalin is used on small parts of acreage, but losses of $431,300 are expected in the West (table 24) in addition to a loss of consumer surplus of $553,800. Growers in other regions would gain because of increases in prices, and the total welfare loss amounts to $909,200.

Paraquat

The contact herbicide paraquat is applied in spring for rapid control of existing foliage. It is used on about 40% of the acreage, and a loss of paraquat would have no yield or quality impacts and only small cost of production impacts. Economic losses of banning paraquat are at $151,500 rather small (table 25).

Simazine

Simazine is the preemergence herbicide that is often rotated with diuron, and banning simazine will lead to increased use of diuron. As a result, diuron resistance could become a concern when simazine is banned. Major quality losses due to a loss of simazine are expected in the West where growers suffer significant losses of $3.8 mill. (table 26). Consumers would also be severely affected by the reduction of apples available for fresh consumption and total first-year welfare impacts amount to $8.0 mill.

Conclusion

In this paper we have developed a methodology for assessing welfare impacts of pesticide use cancellations in apple production. Our framework provides a means of assessment when complex relationships between different marketing channels are important. We implement the model to estimate welfare changes due to fungicide and herbicide cancellations in apple production.

Our simulations show that consumers bear a large share of the overall welfare losses in the fresh market because of the relatively inelastic demand, whereas producers bear the larger share in the processing market. Furthermore, changes in net imports are significant, especially for processed apples, and it is important to acknowledge them in the assessment.

The results highlight the importance of considering impacts by region and distinguishing between seasonal and outright cancellations. In several scenarios, growers in some regions would gain from a pesticide ban because losses by users of pesticides in those regions are out-weighted by gains accruing to non-users. In particular, a reduction in the supply from western states can have large impacts on prices and hence benefit growers in other regions (simazine and oryzalin). This is not surprising since the West produces 61% of all apples produced in the United States.

The economically most important herbicides are glyphosate and simazine a hypothetical ban of which implies welfare losses of $9.6 mill. and $8.0 mill., respectively. For fungicides, EBI fungicides are most important and a loss of these induces an estimated welfare loss of $5.8 mill. Captan and mancozeb are also very important with surplus losses of $2.6 mill. and $1.6 mill., respectively. In many instances, the states east of the Mississippi will be most affected from a fungicide use cancellation. Western states carry a larger share of the losses only in the case of a hypothetical ban on EBI. Overall, this confirms our impression from the study of production systems, which suggested that disease problems are less important in the arid western growing regions.

It is shown that an increase of the preharvest interval for fungicides can lead to a significant reduction of the cost of regulation (mancozeb, dodine, ziram, and EBI). However, for these cases it is also true that most of the current use occurs during the early season. An assessment of consumer risk reduction from elongated preharvest intervals and an analysis of pesticide perseverance would be needed to conclude if such a cancellation at lower cost would achieve the desired reduction in consumer and environmental risk.

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Notes

[1] The report will consist of five chapters discussing the importance of insecticides, herbicides, fungicides and postharvest chemicals used in apple production. This chapter will be the fifth chapter of the report assessing the economic importance of the pesticides discussed in earlier chapters, thereby drawing on data provided in those chapters. The report will be published through Washington State University and can be obtained through Washington State University or the USDA Office of Pesticide Management. *Project Team Leaders*: Catherine Daniels (Washington State University) and David Rosenberger (Cornell University). *Biological Sections*: Jay Brunner (insects, Washington State University), Jeffrey Derr (weeds, Virginia Tech), Anne Morell (postharvest chemicals, Washington State University), David Rosenberger (diseases and postharvest chemicals, Cornell University). *Economic Section*: David Hennessy (Iowa State University), Vickie McCracken (Washington State University), Jutta Roosen (Iowa State University).

[2] Roosen is a graduate assistant at Iowa State University.

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[4] The 1995 survey covered California, Georgia, Michigan, New Jersey, New York, Oregon, Pennsylvania, South Carolina, and Washington.

[5] The cost data should be interpreted very cautiously. Comparisons of costs of production estimates and the generalization of values as published in extension material are very problematic. Nonetheless, the data suggests very strongly that there are negligible differences in insect control cost and large differences in disease control cost across regions.

[6] With regard to the impacts of pesticide regulation on imports and exports, it should be noted that this model only includes market responses. However, non-tariff barriers exist that restrict the trade of apples with certain pesticide treatment histories. These have been acknowledged to some extent in the prediction of replacement shares of substitute pesticides, but the economic analysis itself does not further acknowledge any restrictions on foreign market accessibility.

[7] As discussed in Just, Hueth, and Schmitz the two approaches are in general not equivalent in empirical applications. The approach chosen has the advantage that the assumption of necessity of the output is not made. In addition, for the empirical application the supply

curve is shifted in both market and in this instance the approach chosen is easier to implement.

[8] The states included in the following analysis account for 97.6% of U.S. total production. Impacts in remaining states are negligible in the overall impacts and can safely be ignored in this analysis.

[9] No survey responses are obtained from experts in California for the case of fungicide cancellations and from experts in Ohio for the case of herbicide cancellations. Since current use data is available for these states, we estimate the replacement scenario data using estimates for Washington in the case of fungicides in California and estimates for Michigan in the case of herbicides in Ohio. These extrapolations seem suitable, as production systems are very similar in Washington and California, and Ohio and Michigan. The similarity is reflected in current pesticide use patterns (U.S. Department of Agriculture. NASS/ERS).

[10] The problem with this approach is that such benefits might in fact be larger or might also accrue to pesticides for that we can show a marginal-cost increase. It seems, however, to be the best feasible solution to the problem of nonquantifiable benefits. As a result, we might not completely capture the welfare costs of a pesticide cancellation, and so it is acknowledged that our estimates would underestimate the true cost.

[11] Flexibilities could not be estimated directly because of the dynamic structure of the model on the supply side.

[12] For the fungicides the entire Southeast, Virginia and West Virginia, and New England have each been treated as "one state", i.e. biological impacts have been calculated for the

respective region and enter as such into the analysis. For the herbicide analysis the same holds true for the Northeast and the Southeast.

[13] The organization of the NAPIAP project resulted in different regional organization of the biological impact data for herbicides and fungicides. To make our economic results for fungicides and herbicides comparable, we extrapolate the data and form the same regions for both sections of the study. The fungicide survey obtains data for CA, WA, OR, MI, OH, New England, NY, VA, WV, PA, NC, and SC. The herbicide survey includes data from CA, WA, OR, MI, OH, NY, VA, WV, PA, and NC. In the herbicide section we therefore use marginal-cost impact estimates of NY also for the New England states, and the estimates for NC for the entire Southeast region. Again, this extrapolation seems appropriate because production systems in the respective regions are very similar.

[14] The total cost of canceling the use of a fungicide for the whole season is calculated as the sum of impacts of canceling it for the early season and for the summer season. Lichtenberg, Spear, and Zilberman have shown that an increase of the preharvest interval might lead to an increase in preventive pesticide applications earlier in the season. We ignore such possible effects in our analysis because of difficulties in collecting the necessary data.

Table 1. Production and Revenue by State and Region, 1994-96

	Revenue $ mill.	Acreage 000 acres	Yield 000 lb./acre	Total Prod. mill. lb.	Fresh Prod. mill. lb.	Proc. Prod. mill. lb.	Fresh Share %	Fresh Price $/lb.	Proc. Price $/lb.
WA	938.2	152.7	35.4	5400.0	3900.0	1500.0	0.72	0.212	0.074
CA	149.1	35.2	26.5	933.3	326.7	606.7	0.35	0.325	0.071
OR	18.5	8.6	18.6	159.7	118.3	41.3	0.74	0.131	0.074
West	**1105.9**	**196.5**	**33.0**	**6493.0**	**4345.0**	**2148.0**	**0.67**	**0.218**	**0.073**
MI	100.2	54.3	18.2	988.3	315.0	673.3	0.32	0.148	0.080
OH	21.4	7.7	13.0	100.0	78.3	21.7	0.78	0.255	0.068
Midwest	**121.7**	**62.0**	**17.6**	**1088.3**	**393.3**	**695.0**	**0.36**	**0.170**	**0.079**
NY	134.7	57.3	18.8	1080.0	490.0	590.0	0.45	0.181	0.078
New England	46.4	20.5	11.4	233.2	163.5	69.7	0.70	0.253	0.073
North-East	**181.1**	**77.8**	**16.9**	**1313.2**	**653.5**	**659.7**	**0.50**	**0.199**	**0.077**
PA	46.8	22.0	19.6	430.3	131.7	298.7	0.31	0.179	0.078
VA	32.4	18.8	16.9	317.0	98.3	218.7	0.31	0.152	0.080
WV	14.6	9.7	13.7	133.3	31.7	101.7	0.24	0.212	0.077
Mid-Atlantic	**140.8**	**79.0**	**16.8**	**1331.0**	**391.7**	**939.3**	**0.29**	**0.171**	**0.079**
NC	23.3	9.3	25.8	240.0	72.0	168.0	0.30	0.158	0.071
SC	6.6	3.6	14.4	51.7	21.3	30.4	0.41	0.209	0.070
KY	3.1	2.4	5.4	13.0	8.6	4.4	0.66	0.294	0.139
GA [a]	2.9	2.4	10.8	26.0	9.3	16.7	0.36	[b]	[b]
TN [a]	2.6	1.6	7.7	12.3	9.6	2.7	0.78	0.248	[b]
South-East	**38.5**	**19.3**	**17.8**	**343.0**	**120.8**	**222.2**	**0.35**	**0.186**	**0.072**

[a] Regional averages are employed if a price is not available.

[b] Prices received for fresh or processed apples are not recorded in these states.

Table 2. First-Year Economic Surplus Changes, dMC = $0.01

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-1,397.0	626.0	-437.0	1,063.1	-5.4	-2,023.1	-2,402.0	378.9	-34.4
Midwest	-28.0	-72.2	-103.8	31.6	-1.9	44.2	-15.2	59.4	-0.8
Northeast	-349.3	-381.2	-491.2	109.9	-2.5	32.0	-15.0	47.0	-0.7
M-Atlantic	-194.7	-222.0	-267.5	45.5	-1.5	27.3	-17.0	44.3	-0.7
Southeast	-62.5	-73.9	-94.3	20.4	-0.5	11.4	-4.4	15.8	-0.3
Prod.	**-2,031.6**	**-123.3**	**-1,393.8**	**1,270.5**	**-11.8**	**-1,908.3**	**-2,453.6**	**545.3**	**-36.9**
Cons.	-5,462.9	-4,581.8			-6.7	-881.1			-14.7
Total	**-7,494.5**	**-4,705.1**				**-2,789.3**			

Table 3. Fifth-Year Economic Surplus Changes, dMC = $0.01

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-24,061.0	-11,280.3	-11,282.3	2.1	-86.0	-12,780.7	-12,781.4	0.7	-203.8
Midwest	337.1	261.1	261.0	0.1	2.5	76.0	75.9	0.1	-6.8
Northeast	-424.3	-88.8	-88.9	0.2	-0.7	-335.5	-335.6	0.1	-10.6
M-Atlantic	-111.8	11.8	11.7	0.1	0.1	-123.5	-123.6	0.1	-7.4
Southeast	-13.7	35.3	35.2	0.0	0.2	-49.0	-49.0	0.0	-2.9
Prod.	**-24,273.6**	**-11,060.9**	**-11,063.4**	**2.4**	**-83.9**	**-13,212.7**	**-13,213.7**	**1.0**	**-231.6**
Cons.	-37,877.6	-32,388.3			-47.7	-5,489.2			-92.1
Total	**-62,151.2**	**-43,449.3**				**-18,702.0**			

Table 4. Cost, Yield and Quality Changes after Fungicide Losses[a]

			Summer				Whole Season			
	Acreage Treated	Use in Early Season	Change in Cost	Change in Yield	Change in Fresh Share		Change in Cost	Change in Yield	Change in Fresh Share	
	%	%	$/acre	%	%		$/acre	%	%	
Captan										
CA	26.5	97.5	-0.6	0.0	0.0	*	13.8	0.0	0.0	
WA	7.5	97.5	-0.1	0.0	0.0	*	17.8	0.0	0.0	
OR	9.5	97.5	-0.8	0.0	0.0	*	14.0	0.0	0.0	
MI	91.0	20.0	272.4	0.0	0.0		287.8	0.0	0.0	
OH	91.0	50.0	-6.1	0.0	0.0	*	-14.6	0.0	0.0	*
N-Engl.	99.0	30.0	10.1	0.0	0.0		11.6	0.0	-0.5	
NY	77.5	45.0	36.6	0.0	-0.3		69.5	0.0	-0.6	
PA	77.0	20.0	-2.5	0.0	-1.4		-2.5	0.0	-1.4	
VA/WV	90.0	20.0	-7.6	0.0	-0.8		-8.4	0.0	-1.2	
SE	95.3	15.0	79.5	-2.5	-4.3		76.0	-2.5	-6.0	
Mancozeb										
CA	28.5	100.0	0.0	0.0	0.0		24.5	0.0	0.0	
WA	17.0	100.0	0.0	0.0	0.0		19.2	0.0	0.0	
OR	9.5	99.0	25.2	0.0	0.0		37.6	0.0	-4.0	
MI	22.5	95.0	-1.9	0.0	0.0	*	219.2	-2.3	-9.2	
OH	22.5	95.0	-0.3	0.0	0.0	*	-2.3	0.0	0.0	*
N-Engl.	95.0	95.0	31.5	0.0	0.0		29.4	-0.3	-0.8	
NY	82.0	94.0	20.4	0.0	0.0		85.2	-1.0	0.0	
PA	32.5	90.0	-0.3	0.0	0.0	*	2.2	0.0	-1.1	
VA/WV	90.0	85.0	-0.5	-0.9	-1.9		-0.5	-0.9	-2.1	
SE	39.3	50.0	18.5	0.6	0.0		6.2	0.5	-0.9	
Dodine										
CA	0.0	100.0	0.0	0.0	0.0		0.0	0.0	0.0	
WA	4.5	100.0	0.0	0.0	0.0		46.2	0.0	-3.2	
OR	33.0	97.5	-0.4	0.0	0.0	*	-15.6	0.0	0.0	*
MI	9.0	100.0	0.0	0.0	0.0		1.3	0.0	0.0	
OH	9.0	100.0	0.0	0.0	0.0		-28.5	0.0	0.0	*
N-Engl.	30.0	100.0	0.0	0.0	0.0		-4.7	2.0	2.0	*
NY	9.5	97.5	1.4	0.0	0.0		55.7	0.0	0.5	
PA	31.0	100.0	0.0	0.0	0.0		13.3	0.0	0.0	
VA/WV	5.0	100.0	0.0	0.0	0.0		7.1	0.0	-0.2	
SE	8.0	90.0	0.0	0.0	0.0		49.4	0.0	0.0	

[a] Asterisks mark instances in which marginal cost changes calculated according to equation (6) are negative and are hence set to zeros.

Table 4 (continued)

	Acreage Treated	Use in Early Season	Summer				Whole Season			
			Change in Cost	Change in Yield	Change in Fresh Share		Change in Cost	Change in Yield	Change in Fresh Share	
	%	%	$/acre	%	%		$/acre	%	%	
Ziram										
CA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
WA	36.0	60.0	10.3	0.0	0.0		30.0	0.0	0.0	
OR	13.5	25.0	-6.0	0.0	0.0	*	-4.4	0.0	0.0	*
MI	17.0	50.0	6.2	0.0	0.0		13.9	0.0	0.0	
OH	17.0	50.0	2.6	0.0	0.0		2.6	0.0	0.0	
N-Engl.	25.0	0.0	-11.7	0.0	0.0	*	-11.7	0.0	0.0	*
NY	13.5	7.5	53.9	-0.5	-0.7		57.2	-0.5	-0.7	
PA	46.5	10.0	3.9	0.0	1.8	*	4.2	0.0	2.0	*
VA/WV	80.0	60.0	-7.0	-0.1	-0.7		-7.0	-0.1	-1.2	
SE	64.0	5.0	28.0	0.9	-3.5		28.0	0.9	-3.5	
Benomyl										
CA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
WA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
OR	6.0	100.0	0.0	0.0	0.0		0.0	0.0	0.0	
MI	25.0	10.0	8.1	0.0	0.0		8.1	0.0	0.0	
OH	25.0	10.0	-0.6	0.0	0.0	*	-0.4	0.0	0.0	*
N-Engl.	45.0	25.0	6.4	-0.1	-0.1		6.4	-0.1	-0.1	
NY	38.5	10.0	57.0	0.0	-1.3		62.0	0.0	-1.0	
PA	23.5	30.0	-3.9	0.0	0.0	*	-5.5	0.0	0.0	*
VA/WV	30.0	10.0	41.1	0.0	-0.5		43.3	0.0	-0.5	
SE	51.5	0.0	5.8	0.0	0.0		5.8	0.0	0.0	
EBI										
CA	5.5	82.5	23.5	-1.3	-1.3		57.9	-3.3	-4.0	
WA	25.5	82.5	23.9	-1.3	-1.3		59.9	-3.3	-4.0	
OR	55.5	75.0	31.9	0.0	-10.0		51.6	0.0	-20.0	
MI	50.5	95.0	0.0	0.0	0.0		309.9	0.0	0.0	
OH	50.5	95.0	-3.0	0.0	0.0	*	30.1	0.0	0.0	
N-Engl.	47.5	100.0	0.0	0.0	0.0		-16.9	0.0	0.0	*
NY	45.0	95.0	10.9	0.0	-0.9		113.4	0.0	-1.9	
PA	42.5	90.0	-1.8	0.0	0.0	*	10.7	-1.4	-3.3	
VA/WV	21.9	85.0	-5.9	0.0	0.0	*	4.7	-2.2	-2.0	
SE	57.8	85.0	0.0	0.0	0.0		-12.7	-1.4	-1.3	

Table 4 (continued)

	Acreage Treated	Use in Early Season	Summer: Change in Cost	Summer: Change in Yield	Summer: Change in Fresh Share		Whole Season: Change in Cost	Whole Season: Change in Yield	Whole Season: Change in Fresh Share	
	%	%	$/acre	%	%		$/acre	%	%	
Thiophanate-Methyl										
CA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
WA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
OR	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
MI	12.5	10.0	2.3	0.0	0.0		2.3	0.0	0.0	*
OH	12.5	10.0	-3.7	0.0	0.0	*	-3.7	0.0	0.0	*
N-Engl.	50.0	32.5	-1.3	0.0	0.0	*	-3.7	0.0	0.0	*
NY	20.0	17.5	34.8	0.0	0.5		44.4	0.0	-0.8	
PA	56.0	30.0	11.9	0.0	0.0		11.9	0.0	0.0	
VA/WV	20.0	0.0	0.3	0.0	-0.5		0.3	0.0	-0.5	
SE	31.5	0.0	4.0	0.0	0.0		4.0	0.0	0.0	

Table 5. First-Year Economic Surplus Changes after a Ban on Captan for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	1,609.7	1,453.9	126.4	1,327.5	2.9	155.7	14.2	141.5	1.9
Midwest	-577.4	-388.5	-392.9	4.4	-8.7	-188.9	-189.8	0.9	-2.4
Northeast	-53.3	-39.2	-67.4	28.2	-0.3	-14.1	-15.5	1.4	-0.2
M-Atlantic	29.4	29.7	18.8	10.9	0.2	-0.3	-1.4	1.1	0.0
Southeast	-279.9	-235.4	-236.8	1.4	-1.5	-44.5	-44.6	0.1	-0.6
Prod.	**728.5**	**820.5**	**-552.0**	**1,372.5**	**-7.4**	**-92.0**	**-237.0**	**145.1**	**-1.5**
Cons.	-2,901.9	-2,866.3			-4.2	-35.5			-0.6
Total	**-2,173.4**	**-2,045.8**				**-127.5**			

Table 6. First-Year Economic Surplus Changes after a Ban on Captan for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	1,842.3	1,690.8	157.5	1,533.3	3.4	151.5	-17.7	169.2	1.7
Midwest	-602.8	-405.5	-410.5	5.0	-9.1	-197.3	-198.5	1.2	-2.6
Northeast	-224.7	-194.2	-226.8	32.6	-1.3	-30.5	-32.4	1.8	-0.5
M-Atlantic	30.7	30.7	18.1	12.6	0.2	-0.1	-1.5	1.4	-0.1
Southeast	-320.6	-269.9	-271.5	1.7	-1.7	-50.7	-50.8	0.1	-0.7
Prod.	**724.9**	**852.0**	**-733.2**	**1,585.2**	**-8.6**	**-127.1**	**-300.8**	**173.7**	**-2.1**
Cons.	-3,366.5	-3,315.2			-4.9	-51.3			-0.9
Total	**-2,641.5**	**-2,463.2**				**-178.3**			

Table 7. First-Year Economic Surplus Changes after a Ban on Mancozeb for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	162.0	147.5	23.3	124.2	0.3	14.5	0.9	13.6	0.2
Midwest	6.1	5.0	1.1	3.9	0.1	1.1	0.3	0.9	0.0
N-East	-121.8	-109.6	-112.2	2.5	-0.7	-12.1	-12.3	0.1	-0.2
M-Atlantic	-83.8	-69.5	-72.2	2.7	-0.5	-14.3	-14.6	0.3	-0.2
S-East	0.0	0.2	-1.7	1.9	0.0	-0.3	-0.4	0.2	0.0
Prod.	**-37.4**	**-26.4**	**-161.7**	**135.2**	**-0.8**	**-11.0**	**-26.1**	**15.1**	**-0.2**
Cons.	-301.5	-297.2			-0.4	-4.4			-0.1
Total	**-339.0**	**-323.6**				**-15.4**			

Table 8. First-Year Economic Surplus Changes after a Ban on Mancozeb for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	896.9	870.4	156.5	713.9	1.6	26.5	-60.1	86.6	0.0
Midwest	-181.1	-121.0	-143.2	22.2	-2.8	-60.2	-66.7	6.6	-0.8
N-East	-515.5	-463.9	-478.3	14.4	-3.0	-51.6	-52.6	1.0	-0.7
M-Atlantic	-68.0	-55.4	-70.6	15.2	-0.4	-12.6	-14.8	2.2	-0.2
S-East	11.1	10.4	-0.6	10.9	0.1	0.7	-0.5	1.2	0.0
Prod.	**143.3**	**240.5**	**-536.2**	**776.7**	**-4.4**	**-97.2**	**-194.9**	**97.7**	**-1.7**
Cons.	-1,756.1	-1,714.8			-2.5	-41.3			-0.7
Total	**-1,612.8**	**-1,474.3**				**-138.5**			

Table 9. First-Year Economic Surplus Changes after a Ban on Dodine for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	0.6	0.6	0.0	0.5	0.0	0.1	0.0	0.1	0.0
Midwest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northeast	-0.8	-0.7	-0.8	0.1	0.0	-0.1	-0.1	0.0	0.0
M-Atlantic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Southeast	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prod.	**-0.1**	**-0.1**	**-0.7**	**0.6**	**0.0**	**0.0**	**-0.1**	**0.1**	**0.0**
Cons.	-1.1	-1.1			0.0	0.0			0.0
Total	**-1.2**	**-1.2**				**0.0**			

Table 10. First-Year Economic Surplus Changes after a Ban on Dodine for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-111.4	-35.4	-127.8	92.4	-0.4	-75.9	-103.8	27.8	-1.3
Midwest	7.0	2.8	0.1	2.7	0.1	4.3	0.3	4.0	0.0
Northeast	-14.4	-15.2	-24.0	8.8	-0.1	0.8	-2.2	3.0	0.0
M-Atlantic	-1.3	-3.1	-6.6	3.5	0.0	1.8	-0.8	2.7	0.0
Southeast	-3.0	-3.2	-5.0	1.8	0.0	0.3	-0.8	1.1	0.0
Prod.	**-123.0**	**-54.2**	**-163.3**	**109.1**	**-0.5**	**-68.8**	**-107.4**	**38.5**	**-1.3**
Cons.	-237.4	-205.7			-0.3	-31.7			-0.5
Total	**-360.4**	**-259.9**				**-100.5**			

Table 11. First-Year Economic Surplus Changes after a Ban on Ziram for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	53.1	73.8	-10.8	84.7	0.0	-20.7	-35.7	15.0	-0.4
Midwest	4.1	2.5	-1.0	3.4	0.0	1.6	-0.4	2.0	0.0
N-East	-51.0	-46.6	-58.4	11.8	-0.3	-4.4	-6.0	1.6	-0.1
M-Atlantic	1.8	0.9	-1.1	2.1	0.0	0.8	0.2	0.6	0.0
S-East	-75.3	-64.2	-65.2	0.9	-0.4	-11.1	-11.3	0.2	-0.2
Prod.	**-67.3**	**-33.6**	**-136.5**	**102.9**	**-0.7**	**-33.7**	**-53.2**	**19.5**	**-0.6**
Cons.	-272.1	-256.6			-0.4	-15.5			-0.3
Total	**-339.4**	**-290.2**				**-49.2**			

Table 12. First-Year Economic Surplus Changes after a Ban on Ziram for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-37.0	42.6	-89.2	131.7	-0.4	-79.6	-110.5	30.9	-1.4
Midwest	6.2	2.3	-2.9	5.2	0.0	3.9	-0.9	4.8	0.0
N-East	-43.8	-41.7	-59.8	18.1	-0.3	-2.0	-5.9	3.8	-0.1
M-Atlantic	-8.0	-8.8	-12.0	3.2	-0.1	0.8	-0.7	1.5	0.0
S-East	-73.0	-62.8	-64.3	1.4	-0.4	-10.2	-10.7	0.5	-0.2
Prod.	**-155.6**	**-68.5**	**-228.2**	**159.7**	**-1.1**	**-87.1**	**-128.7**	**41.6**	**-1.7**
Cons.	-447.8	-407.8			-0.6	-40.0			-0.7
Total	**-603.4**	**-476.2**				**-127.2**			

Table 13. First-Year Economic Surplus Changes after a Ban on Benomyl for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	189.3	171.8	0.3	171.5	0.3	17.5	0.0	17.5	0.2
Midwest	1.6	2.2	-2.1	4.3	0.0	-0.6	-1.3	0.8	0.0
Northeast	-188.6	-169.8	-181.5	11.7	-1.1	-18.8	-19.3	0.4	-0.2
M-Atlantic	-27.6	-22.3	-28.1	5.7	-0.2	-5.3	-5.8	0.5	-0.1
Southeast	-0.7	-0.3	-2.0	1.7	0.0	-0.5	-0.6	0.1	0.0
Prod.	**-26.0**	**-18.4**	**-213.3**	**194.9**	**-0.9**	**-7.6**	**-26.9**	**19.2**	**-0.1**
Cons.	-340.8	-338.0			-0.5	-2.8			0.0
Total	**-366.9**	**-356.4**				**-10.5**			

Table 14. First-Year Economic Surplus Changes after a Ban on Benomyl for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	190.5	172.8	0.3	172.6	0.3	17.6	0.0	17.6	0.2
Midwest	1.7	2.2	-2.1	4.3	0.0	-0.6	-1.3	0.8	0.0
Northeast	-188.5	-169.7	-181.4	11.7	-1.1	-18.8	-19.3	0.4	-0.2
M-Atlantic	-29.2	-23.7	-29.4	5.8	-0.2	-5.5	-6.0	0.5	-0.1
Southeast	-0.7	-0.2	-2.0	1.8	0.0	-0.5	-0.6	0.1	0.0
Prod.	**-26.2**	**-18.5**	**-214.6**	**196.1**	**-0.9**	**-7.7**	**-27.1**	**19.4**	**-0.1**
Cons.	-343.0	-340.2			-0.5	-2.9			0.0
Total	**-369.3**	**-358.6**				**-10.6**			

Table 15. First-Year Economic Surplus Changes after a Ban on EBI Fungicides for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-632.2	-196.8	-511.8	315.0	-2.6	-435.4	-552.1	116.7	-7.3
Midwest	36.1	12.6	6.4	6.2	0.3	23.5	11.9	11.6	0.0
N-East	-19.8	-30.7	-54.6	23.8	-0.2	10.9	0.7	10.2	-0.1
M-Atlantic	35.6	18.1	5.8	12.3	0.1	17.5	5.6	12.0	0.0
S-East	14.4	8.1	4.7	3.4	0.1	6.2	3.6	2.6	0.0
Prod.	**-565.9**	**-188.7**	**-549.5**	**360.7**	**-2.4**	**-377.2**	**-530.3**	**153.1**	**-7.3**
Cons.	-1,087.1	-912.5			-1.3	-174.6			-2.9
Total	**-1,653.1**	**-1,101.3**				**-551.8**			

Table 16. First-Year Economic Surplus Changes after a Ban on EBI Fungicides for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-740.3	362.7	-1,153.8	1,516.5	-4.9	-1,103.0	-1,494.3	391.3	-18.8
Midwest	-261.0	-205.7	-237.2	31.5	-4.8	-55.3	-90.3	35.0	-1.5
N-East	-160.0	-174.6	-293.7	119.1	-1.2	14.6	-15.7	30.3	-0.5
M-Atlantic	21.0	-11.7	-72.2	60.6	-0.1	32.7	-3.0	35.7	-0.2
S-East	23.2	10.0	-7.1	17.1	0.1	13.2	5.4	7.8	0.0
Prod.	**-1,117.1**	**-19.3**	**-1,764.2**	**1,744.8**	**-10.9**	**-1,097.8**	**-1,597.9**	**500.1**	**-21.0**
Cons.	-4,724.0	-4,222.2			-6.2	-501.7			-8.3
Total	**-5,841.0**	**-4,241.6**				**-1,599.5**			

Table 17. First-Year Economic Surplus Changes after a Ban on Thiophanate-Methyl for Summer Applications

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	36.3	32.8	0.0	32.8	0.1	3.5	0.0	3.5	0.0
Midwest	0.6	0.6	-0.3	1.0	0.0	0.0	-0.2	0.2	0.0
Northeast	-27.7	-24.9	-27.6	2.7	-0.2	-2.8	-2.9	0.1	0.0
M-Atlantic	-14.1	-11.7	-12.6	0.9	-0.1	-2.4	-2.5	0.1	0.0
Southeast	-1.2	-1.0	-1.4	0.5	0.0	-0.2	-0.3	0.0	0.0
Prod.	**-6.0**	**-4.1**	**-41.9**	**37.9**	**-0.2**	**-1.9**	**-5.9**	**3.9**	**0.0**
Cons.	-65.5	-64.7			-0.1	-0.8			0.0
Total	**-71.5**	**-68.8**				**-2.7**			

Table 18. First-Year Economic Surplus Changes after a Ban on Thiophanate-Methyl for the Entire Season

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	68.8	62.4	0.0	62.4	0.1	6.4	0.0	6.4	0.1
Midwest	1.8	1.6	-0.2	1.8	0.0	0.2	-0.2	0.3	0.0
Northeast	-69.2	-62.3	-67.4	5.1	-0.4	-6.9	-7.1	0.2	-0.1
M-Atlantic	-12.6	-10.3	-12.1	1.8	-0.1	-2.3	-2.5	0.2	0.0
Southeast	-0.5	-0.3	-1.2	0.9	0.0	-0.2	-0.3	0.1	0.0
Prod.	**-11.8**	**-8.9**	**-80.9**	**72.0**	**-0.3**	**-2.9**	**-10.0**	**7.1**	**0.0**
Cons.	-123.9	-122.8			-0.2	-1.1			0.0
Total	**-135.6**	**-131.7**				**-3.9**			

Table 19. Cost, Yield and Quality Changes after Herbicide Losses[a]

	Acreage Treated %	Change in Cost ($/acre)	Change in Yield %	Change in Fresh Share %	
2,4 D					
CA	4	-9.00	0	0	*
WA	16	17.36	0	0	
OR	30	21.01	0	0	
MI	12	6.04	0	0	
OH	13	17.93	0	0	
NY[b]	12	-11.23	0	0	*
PA	45	10.74	0.0135	0	
VA	20	0.40	0	0	
WV	42	-11.95	0	0	*
NC[c]	50	13.04	0	0	
Diuron					
CA	3	3.95	0	0	
WA	20	15.11	0	0	
OR	27	16.08	0	0	
MI	5	4.17	0	0	
OH	10	21.38	0	0	
NY[b]	10	1.96	0	0	
PA	26	14.80	0	0	
VA	20	3.35	0	0	
WV	25	3.78	0	0	
NC[c]	40	10.87	-8.5	0	
Glyphosate					
CA	61	-2.77	-6	0	*
WA	66	7.20	0	-9.3	
OR	58	10.14	0	-9.3	
MI	35	1.65	0	0	
OH	31	-5.43	0	0	*
NY[b]	40	-2.36	0	0	*
PA	6	16.76	-1.44	0	
VA	25	-2.03	0	0	*
WV	27	-8.10	0	0	*
NC[c]	85	9.45	-3	0	

[a] An asterisk marks instances in which marginal cost changes calculated according to equation (6) are negative and are hence set to zeros.
[b] The impact data for NY is also applied to the entire region Northeast.
[c] The impact data for NC is also applied to the entire region Southeast.

Table 19 (continued)

	Acreage Treated %	Change in Cost ($/acre)	Change in Yield %	Change in Fresh Share %	
Norflurazon					
CA	9	-0.37	0	0	*
WA	40	6.88	0	0	
OR	9	13.65	0	0	
MI	9	-7.51	0	0	*
OH	5	-21.98	0	0	*
NY[b]	15	-4.14	0	0	*
PA	8	-6.40	0	0	*
VA	10	-3.06	0	0	*
WV	6	0.35	0	0	
NC[c]	5	-7.02	0	0	*
Oryzalin					
CA	12	-17.09	0	0	*
WA	20	16.04	0	-2.5	
OR	3	7.47	0	-2.5	
MI	9	-0.90	0	0	*
OH	3	-1.66	0	0	*
NY[b]	5	-21.58	0	0	*
PA	0	0.00	0	0	
VA	3	2.18	0	0	
WV	7	4.30	0	0	
NC[c]	5	2.76	0	0	
Paraquat					
CA	38	-8.48	0	0	*
WA	33	9.81	0	0	
OR	33	9.71	0	0	
MI	40	1.01	0	0	
OH	20	2.10	0	0	
NY[b]	25	2.36	0	0	
PA	32	4.45	0	0	
VA	63	2.99	0	0	
WV	40	2.79	0	0	
NC[c]	60	11.77	0	0	

Table 19 (continued)

	Acreage Treated %	Change in Cost ($/acre)	Change in Yield %	Change in Fresh Share %
Simazine				
CA	14	3.11	0	0
WA	50	7.70	0	-9.7
OR	13	8.79	0	-9.7
MI	35	6.72	0	0
OH	18	20.90	0	0
NY[b]	40	7.25	0	0
PA	30	5.90	0	0
VA	40	2.92	0	0
WV	38	4.68	0	0
NC[c]	40	0.43	0	0

Table 20. First-Year Economic Surplus Changes after a Ban on 2,4-D

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-33.3	-7.2	-42.1	34.8	-0.2	-26.1	-35.6	9.6	-0.4
Midwest	1.8	0.9	-0.3	1.1	0.0	1.0	-0.4	1.4	0.0
N-East	5.7	4.4	0.5	3.9	0.0	1.2	0.1	1.1	0.0
M-Atlantic	-5.8	-5.6	-6.7	1.2	0.0	-0.2	-1.0	0.8	0.0
S-East	-8.6	-7.6	-8.0	0.4	0.0	-1.1	-1.3	0.2	0.0
Prod.	**-40.2**	**-15.1**	**-56.5**	**41.4**	**-0.2**	**-25.1**	**-38.2**	**13.0**	**-0.5**
Cons.	-98.0	-86.5			-0.1	-11.5			-0.2
Total	**-138.2**	**-101.6**				**-36.6**			

Table 21. First-Year Economic Surplus Changes after a Ban on Diuron

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	33.2	53.2	-29.0	82.1	0.0	-20.0	-35.6	15.6	-0.4
Midwest	5.8	3.7	0.6	3.1	0.1	2.1	-0.1	2.2	0.0
N-East	11.4	9.8	-0.3	10.1	0.1	1.6	0.0	1.6	0.0
M-Atlantic	-2.6	-2.9	-6.3	3.5	0.0	0.2	-1.0	1.3	0.0
S-East	-110.4	-94.0	-95.2	1.2	-0.6	-16.4	-16.7	0.4	-0.2
Prod.	**-62.6**	**-30.2**	**-130.2**	**100.0**	**-0.5**	**-32.5**	**-53.4**	**21.0**	**-0.6**
Cons.	-221.6	-206.5			-0.3	-15.1			-0.3
Total	**-284.2**	**-236.7**				**-47.5**			

Table 22. First-Year Economic Surplus Changes after a Ban on Glyphosate

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-4,538.4	-1,188.8	-1,862.0	673.2	-14.0	-3,349.6	-3,710.9	361.3	-55.3
Midwest	225.3	52.6	17.4	35.2	1.1	172.7	59.9	112.8	0.1
Northeast	327.9	190.4	76.1	114.2	1.1	137.6	55.0	82.5	0.1
M-Atlantic	204.9	75.9	8.2	67.7	0.5	129.0	20.2	108.9	0.1
Southeast	-8.6	-41.4	-46.7	5.3	-0.3	32.8	25.9	7.0	-0.2
Prod.	**-3,788.8**	**-911.3**	**-1,806.9**	**895.6**	**-11.5**	**-2,877.5**	**-3,549.9**	**672.4**	**-55.2**
Cons.	-5,777.6	-4,459.6			-6.5	-1,318.0			-21.9
Total	**-9,566.4**	**-5,370.9**				**-4,195.5**			

Table 23. First-Year Economic Surplus Changes after a Ban on Norflurazon

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-43.7	-19.3	-33.2	13.8	-0.2	-24.4	-29.9	5.5	-0.4
Midwest	1.9	0.7	0.1	0.6	0.0	1.3	0.1	1.2	0.0
Northeast	3.3	2.3	0.3	2.0	0.0	1.0	0.2	0.9	0.0
M-Atlantic	1.9	0.9	0.1	0.9	0.0	1.0	0.1	0.9	0.0
Southeast	0.8	0.4	0.0	0.4	0.0	0.3	0.0	0.3	0.0
Prod.	**-35.8**	**-15.0**	**-32.7**	**17.7**	**-0.1**	**-20.8**	**-29.5**	**8.7**	**-0.4**
Cons.	-57.8	-48.2			-0.1	-9.5			-0.2
Total	**-93.6**	**-63.2**				**-30.4**			

Table 24. First-Year Economic Surplus Changes after a Ban on Oryzalin

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-431.3	-192.2	-364.0	171.8	-1.5	-239.1	-304.0	64.9	-3.9
Midwest	18.8	6.3	0.5	5.8	0.1	12.5	1.1	11.4	0.0
Northeast	31.7	21.9	1.1	20.8	0.1	9.9	0.5	9.4	0.0
M-Atlantic	18.1	8.8	0.0	8.9	0.1	9.3	0.1	9.1	0.0
Southeast	7.2	3.9	0.0	3.8	0.0	3.3	0.1	3.2	0.0
Prod.	**-355.5**	**-151.4**	**-362.4**	**211.1**	**-1.2**	**-204.1**	**-302.1**	**98.0**	**-3.9**
Cons.	-553.8	-460.4			-0.7	-93.3			-1.6
Total	**-909.2**	**-611.8**				**-297.5**			

Table 25. First-Year Economic Surplus Changes after a Ban on Paraquat

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-33.4	-5.5	-36.1	30.6	-0.2	-27.9	-35.8	7.9	-0.5
Midwest	2.2	0.9	0.0	0.9	0.0	1.4	0.3	1.0	0.0
Northeast	1.5	0.6	-3.1	3.7	0.0	0.9	-0.1	1.0	0.0
M-Atlantic	-14.0	-12.6	-13.6	1.1	-0.1	-1.4	-2.1	0.7	0.0
Southeast	-0.3	-0.5	-1.1	0.5	0.0	0.2	-0.1	0.3	0.0
Prod.	**-44.0**	**-17.2**	**-54.0**	**36.8**	**-0.2**	**-26.8**	**-37.6**	**10.9**	**-0.5**
Cons.	-107.5	-95.4			-0.1	-12.2			-0.2
Total	**-151.5**	**-112.6**				**-38.9**			

Table 26. First-Year Economic Surplus Changes after a Ban on Simazine

	Total	Fresh Apples				Processed Apples			
		Total	User	Non-User	Quantity	Total	User	Non-User	Quantity
	000 $	000 $	000 $	000 $	mill. lb.	000 $	000 $	000 $	mill. lb.
West	-3,756.9	-1,662.0	-2,646.0	984.0	-13.3	-2,094.9	-2,499.3	404.4	-34.3
Midwest	160.5	52.9	15.1	37.8	1.1	107.6	35.8	71.8	0.1
Northeast	257.1	172.7	56.3	116.4	1.0	84.3	32.5	51.8	0.0
M-Atlantic	155.6	74.9	22.5	52.3	0.5	80.7	27.4	53.3	0.1
Southeast	64.7	35.6	14.1	21.5	0.2	29.1	11.6	17.5	0.0
Prod.	**-3,119.1**	**-1,325.9**	**-2,537.9**	**1,212.0**	**-10.5**	**-1,793.2**	**-2,392.0**	**598.7**	**-34.1**
Cons.	-4,883.2	-4,068.3			-6.0	-815.0			-13.6
Total	**-8,002.3**	**-5,394.2**				**-2,608.2**			

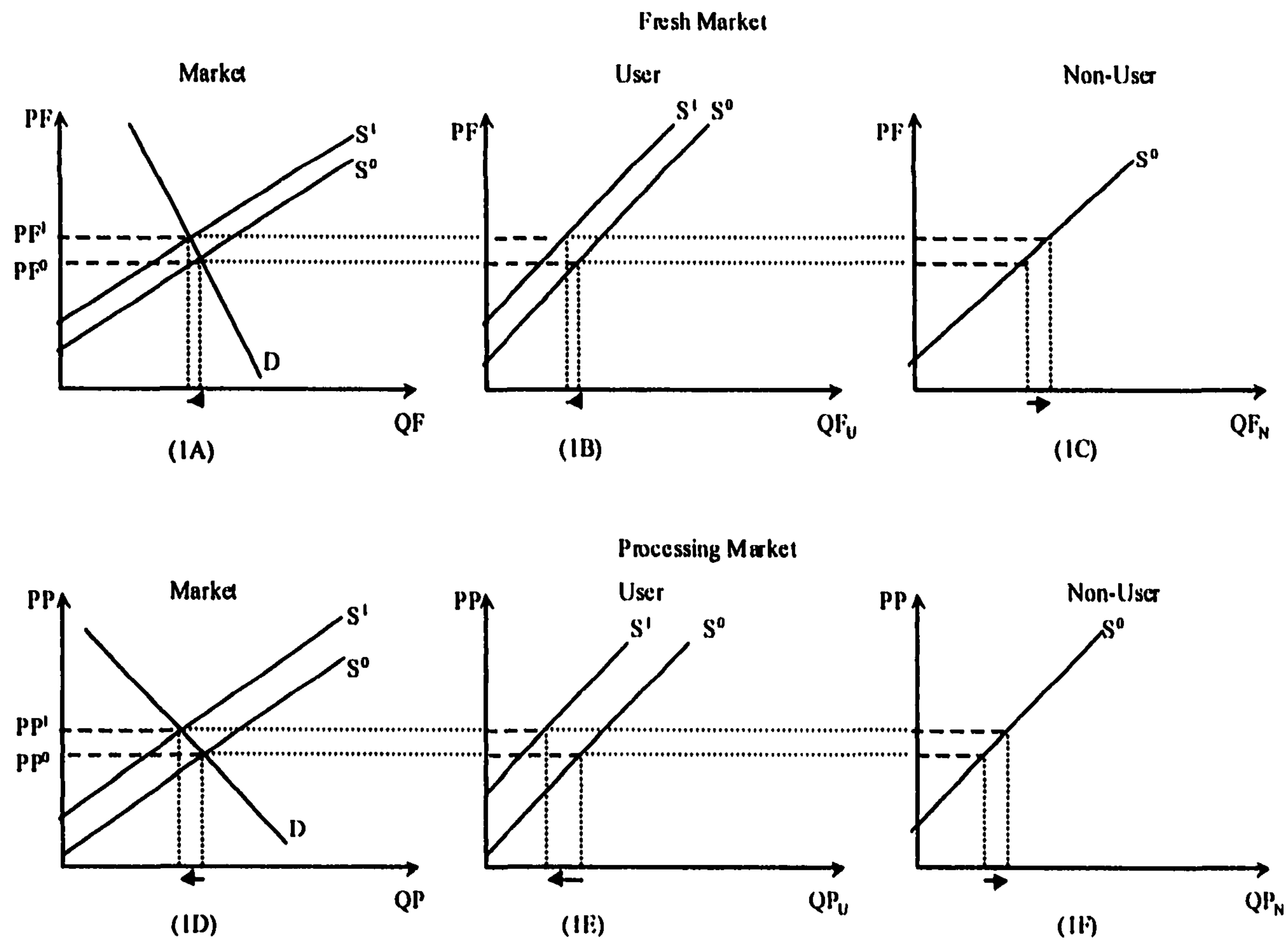


Figure 1. Analysis of a Pesticide Ban: Ignoring Joint Production

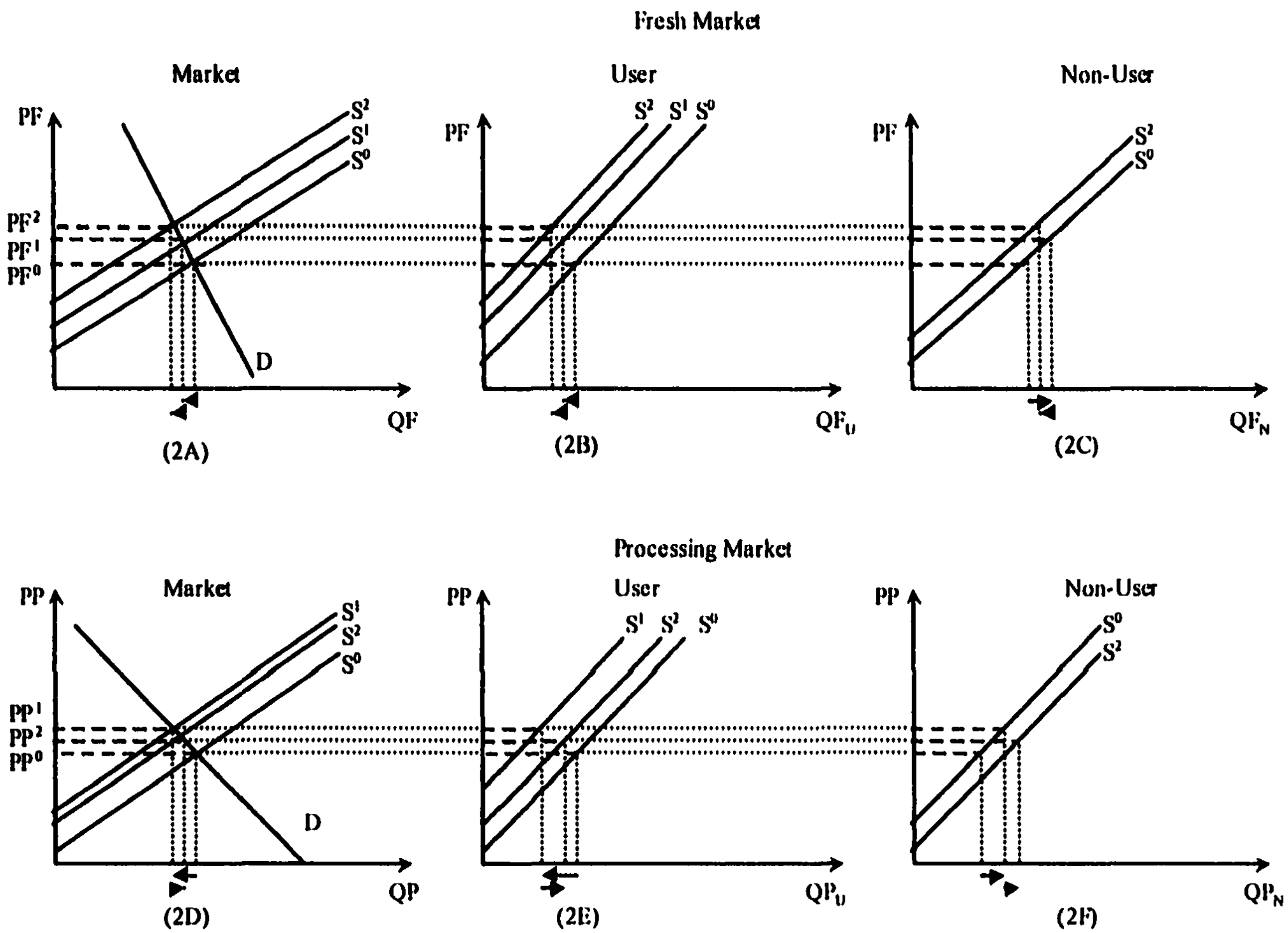
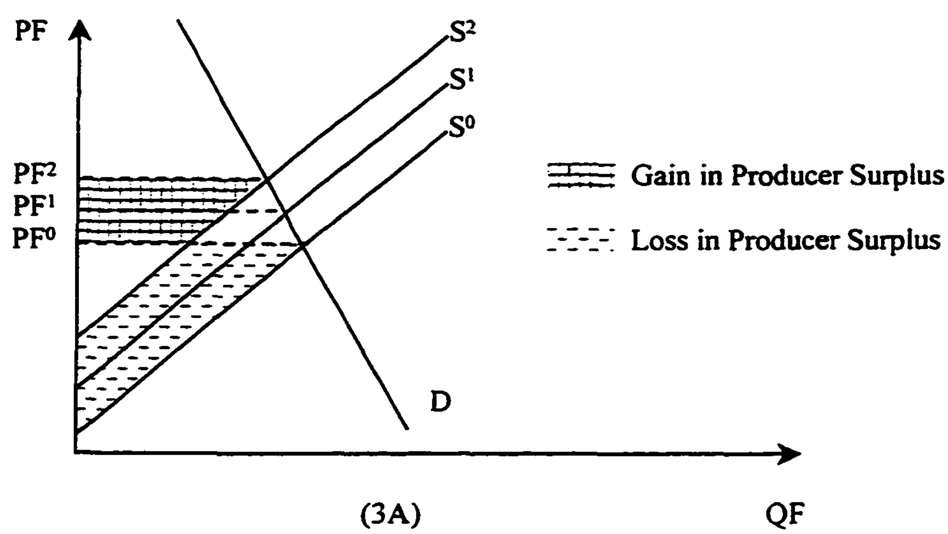


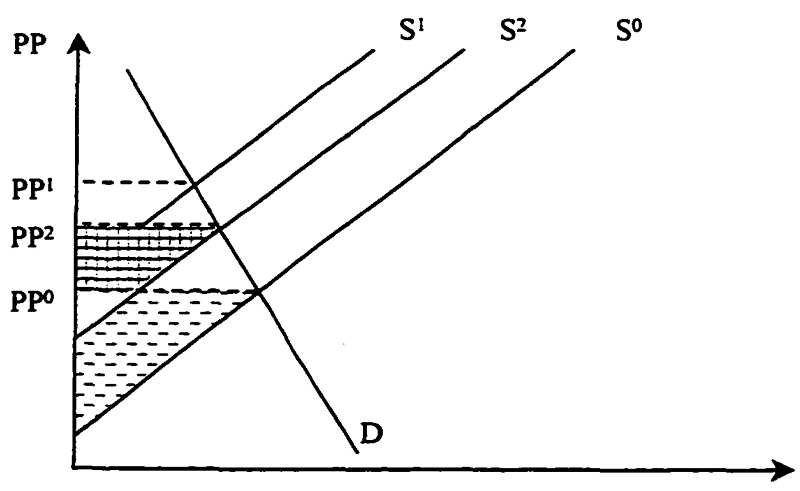
Figure 2. Analysis of a Pesticide Ban: Including Joint Production

Fresh Market



(3A)

Processing Market



(3B)

Figure 3. Welfare Analysis of a Pesticide Use Restriction: Producer Side

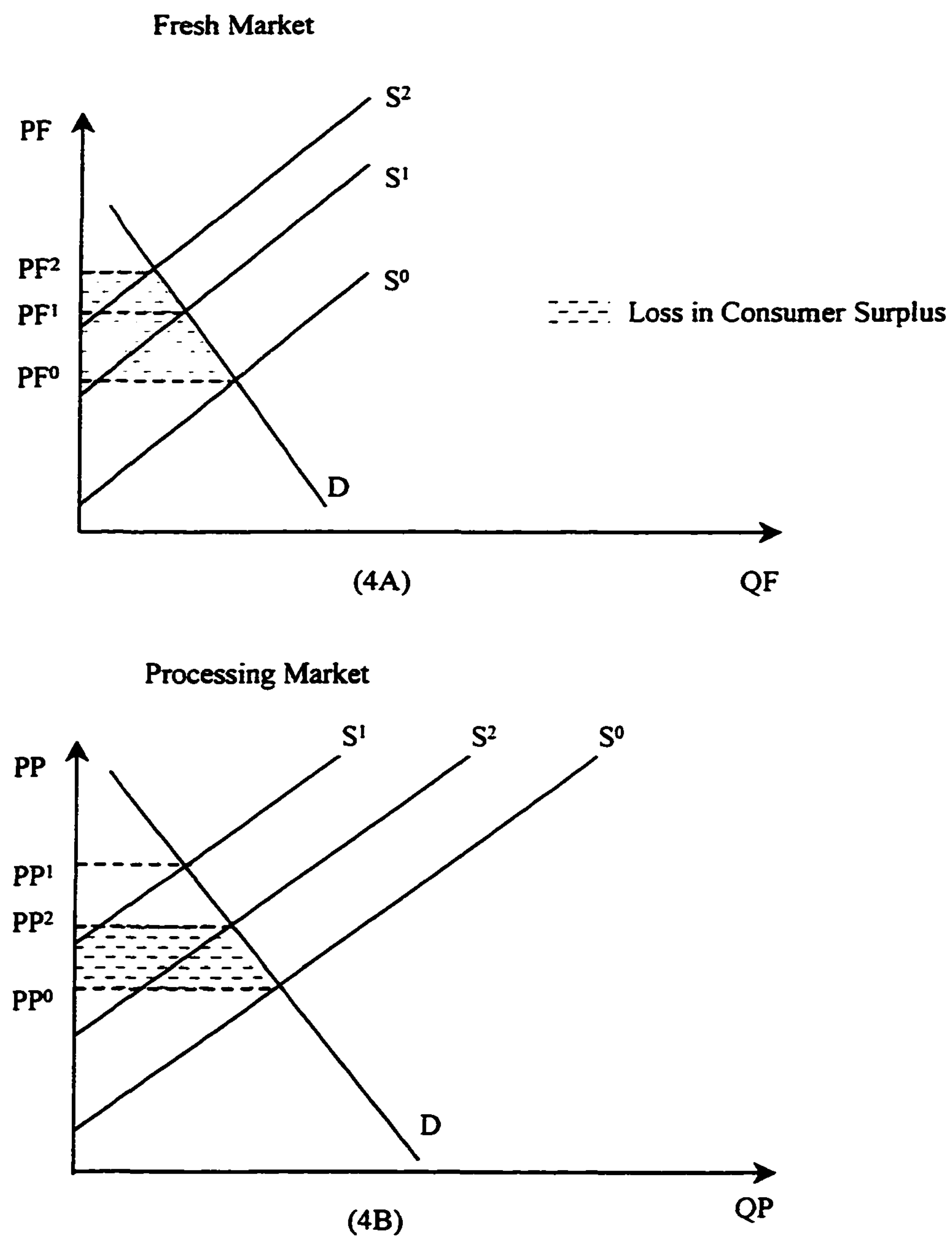


Figure 4. Welfare Analysis of a Pesticide Use Restriction: Consumer Side

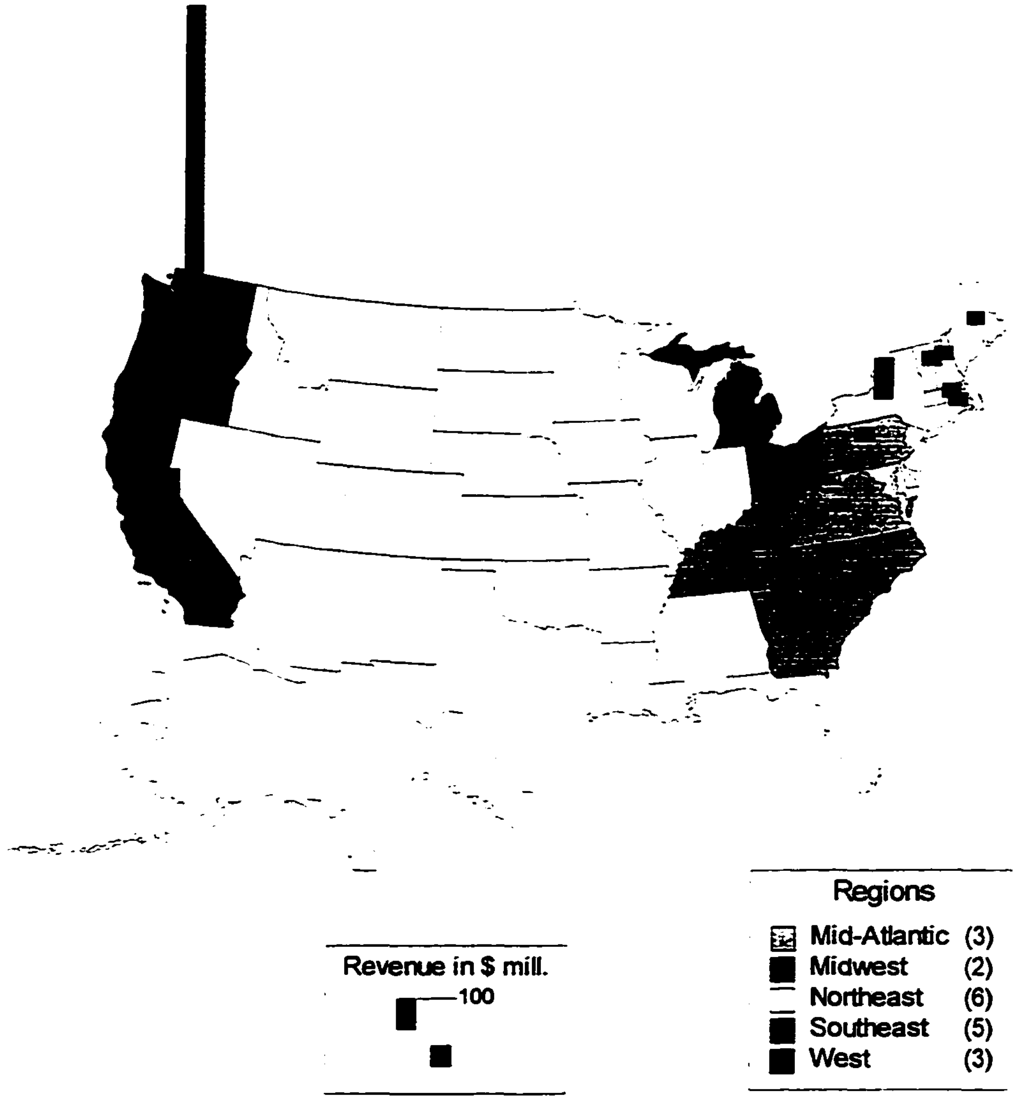


Figure 5. Apple Growing Regions and Revenue from Apple Production by State

Appendix 2A: A Regional Econometric Model of U.S. Apple Supply and Demand

Introduction

Estimation of consumer and producer surplus changes that are caused by technology shifts requires knowledge of demand and supply elasticities in the markets in questions. Because apple production systems are very heterogeneous across the United States, growers' abilities to respond to technology changes and market forces differ widely. To capture the dispersion of responses, estimates of elasticities are needed for the different grower groups. To this end, a model of U.S. apple production was estimated at a regional level.

Several econometric models of the U.S. apple industry exist in the literature, but none of them provides regional elasticity estimates that are suitable for our modeling effort. Willett (1993) estimates an econometric model of the apple industry with a focus on the demand side. Supply is estimated at the aggregated U.S. level. Baumes and Conway (1984) also estimate a model at the aggregated U.S. level, and use their model to demonstrate the effects of a hypothetical pesticide ban. However, their model does not allow for the analysis of regional effects.

Hossain (1993) estimates a model of U.S. apple industry for two regions, dividing the United States into the West/Central (excluding Michigan) and the East (incl. Michigan). The model is specified at the wholesale-retail level. Supply is considered to be fixed in any given period and the model is not useful for the estimation of short-run or long-run production impacts because growers can only adjust to price changes by reallocating fruit from fresh to processed consumption. Chaudhry (1988) estimates a regional model, concentrating on allocation decisions to the fresh and processing market and to the month of sale within a given year. He models production as exogenous in any given year.

Fuchs, Farish, and Bohall (1974) and Dunn and Garafola (1986) simulate regional demand and supply impacts via mathematical programming models. While these models are the only ones whose regional specification would allow modeling regional impacts as desired, mathematical models need a large amount of information and this data is hard to obtain when seeking long-run impacts. Miller (1976) estimates regional price response functions for eight regions of the U.S. in a model of regional competition. He models supply as given.

In general it can be said that although several models of the apple industry exist, most of them are dated and interest is mostly focused on short-term allocation decisions or structural changes in product demand. None of these models is appropriate for the modeling of regional impacts of technology shifts because supply is usually taken as given. The results in this appendix show that production adjustments differ across regions and that this heterogeneity ought to be acknowledged in a welfare assessment of technology changes.

The Model

The structural model is organized into five components: supply, allocation, pricing, demand, and net imports. We divide the United States into four apple production regions, the Northwest, the Southwest, the Central, and the East, as described in table 2A.1, and for each region the total supply and the allocation between markets for fresh and processed utilization are modeled. The demand and net import equations on the other hand are set at the aggregated U.S. level. To link the regional supply components with the demand component, regional pricing equations are introduced that translate U.S. level prices into regional prices. In this section we describe the specification of the model component by component.

Supply

In each production region, supply decisions for a crop are divided into a decision about acreage to be planted and a decision about planned yields. Apple orchards can have a lifetime of several decades and acreage decisions in apple production are expected to be inelastic in the short run. Following French, King, and Minami, we model the change in bearing acreage in region j and year t, ΔAB_t^j, rather than the total bearing acreage, AB_t^j, directly and it is described as a function of past input and output prices, $IPP3_t$ and $PA3_t^j$.

Yield per acre, Y_t^j, is modeled as a function of expected price and a time trend, T, that captures changes in the production technology. Specifically, price expectations are modeled as adaptive expectations and approximated by a three-year moving average of past average prices received, $PA3_t^j$.

Total production for a region, QPT_t^j, is the product of yield and bearing acreage. The general form of the functions describing the supply sector for each region can be summarized as:

$$\Delta AB_t^j = a_{10}^j + a_{11}^j PA3_{t-3}^j / IPP3_{t-3} + \varepsilon_{1t} \qquad (2A.1)$$

$$AB_t^j = AB_{t-1}^j + \Delta AB_t^j \qquad (2A.2)$$

$$Y_t^j = a_{20}^j + a_{21}^j PA3_{t-1}^j + a_{22}^j T + \varepsilon_{2t} \qquad (2A.3)$$

$$QPT_t^j = AB_t^j \cdot Y_y^j \qquad (2A.4)$$

where subscripts t signify the time index and superscripts j denote the region and $IPP3_t$ is the index for prices paid by farmers on the U.S. basis. Greek letters signify error terms in the equations to be estimated and $a_{..}^{j}$ are the parameters to be estimated.

Allocation

The allocation equation estimates the amount of apples sold in the market for fresh apples, QPF_t^j. Explanatory variables include the price premium paid for fresh apples, i.e. the difference of prices paid for fresh and process apples, $PF_t^j - PP_t^j$, and total production in the current year, QPT_t^j. The coefficient to QPT_t^j indicates the share of total production above average total production allocated to fresh consumption, while the coefficient to $PF_t^j - PP_t^j$ measures the change of fresh utilization due to price incentives.

Produce allocated to the processing market is defined as the difference between total and fresh production, so that the allocation component of the model is described by

$$QPF_t^j = a_{30}^j + a_{31}^j (PF_t^j - PP_t^j) + a_{32}^j QPT_t^j + \varepsilon_{3t} \qquad (2A.5)$$

$$QPP_t^j = QPT_t^j - QPF_t^j \qquad (2A.6)$$

Demand

Regional production of fresh and processed apples is aggregated to the U.S. level at which the demand system estimates apple consumption per person in the form of inverse demand functions. The per capita quantities of consumption of fresh apples, QUF_t, and consumption of an alternative fresh fruit, e.g., fresh oranges, enters the estimation of the inverse demand for fresh apples, as do per capita personal food consumption expenditures, $PCEDC_t$. A time trend was also included. Alternative fruits were included to measure substitution effects or changes in taste parameters. The demand for processing apples is specified as a function of processed apple consumption, QUP_t, consumption of an alternative processed fruit, e.g., orange juice, and personal food consumption expenditures.

$$PF_t = d_{10} + d_{11}\, QUF_t + d_{12}\, QUFO_t + d_{13}\, PCEDC_t + d_{14}T + \eta_{1t} \qquad (2A.7)$$

$$PP_t = d_{20} + d_{21}\, QUP_t + d_{22}\, QUJO_t + d_{23}\, PCEDC_t + d_{24}\, T + \eta_{2t} \qquad (2A.8)$$

where $QUFO_t$ denotes fresh orange consumption, and $QUJO_t$ the consumption of orange juice.

Pricing

To link the regional supply sectors of the model to the national demand sector, regional fresh and processing prices are modeled as a linear function of the average U.S. price.

$$PF_t^j = b_{10} + b_{11}PF_t + \beta_{1t} \qquad (2A.9)$$

$$PP_t^j = b_{20} + b_{21}PP_t + \beta_{2t} \qquad (2A.10)$$

Our modeling approach is similar to that of Miller, who estimates a demand function for each region as a function of U.S. supply. Using linear pricing equation jointly with the inverse demand equations, we restrict the differences in the regional demand equations to linear transformations of a common national demand function.

Net Imports

Net imports for fresh and processed apples are modeled as a function of the U.S. price for the respective product, PF_t and PP_t, and the quantities of U.S. fresh and processed production, QPF_t and QPP_t. In addition, the per-unit values of net imports, PIF_t and PIP_t, was included; it is calculated as the value of net imports and exports over the respective total quantity. The equations are of the form:

$$NIF_t = e_{10} + e_{11} PF_t + e_{12} PIF_t + e_{13} QPF_t + e_{14} T + \mu_{1t} \quad (2A.11)$$

$$NIP_t = e_{20} + e_{21} PP_t + e_{22} PIP_t + e_{23} QPP_t + e_{24} T + \mu_{2t} \quad (2A.12)$$

Data

The model is estimated using data from 1971-97. The index of prices paid by farmers (IPP_t) is obtained from U.S. Department of Agriculture, Agricultural Statistics and the import and export data from the U.S. Department of Agriculture, Foreign Agricultural Trade of the United States: Annual Supplement. Production and consumption data are taken from several U.S. Department of Agriculture ERS/CED publications and Johnson. For the estimation all prices, including, IPP_t, are deflated by a GDP deflator (1992=100) taken from the economic report of the U.S. President.

Although apple production statistics are reported for all major production states, some statistics are incomplete for minor states. For the ten major apple producing states (Washington, Michigan, New York, California, Pennsylvania, Virginia, North Carolina, West Virginia, Oregon, and Ohio) that produce 92% of total U.S. apple production all necessary data are available. For some minor states, in which not all statistics are recorded continuously, missing values are filled in and we describe the procedures used in the process.

For bearing acreage, a quadratic trend curve is fitted through the available years of data and the predicted values are used to fill in missing values. The percentage of crop allocated to the fresh market is estimated using a linear regression of fresh production in the state with missing data on fresh allocation in other states of the same region in the same year. This method measures the average percentage going to the fresh market and captures average responses to market, weather, and pest conditions in the region.

Total production data are complete, and yield data are obtained by dividing total production by acreage. Average grower prices are also reported for all states. The price received for fresh apples is not available in every year for all states, and missing values are replaced by regional averages for the given year. The missing value for the processing price is calculated to ensure that the weighted average of processing and fresh prices results in the average price for the state.[1] It should be noted that, since the complete data accounts for more than 90% of U.S. production, filling in the missing data should not have significantly changed the results significantly.

Results

The system is estimated using three-stage least squares. For the supply side, apple production in the United States is segmented into four production regions: Northwest, Southwest, Central, and East and table 2A.1 gives some production statistics for the four regions. The estimated model is presented in table 2A.2 and the numbers in parentheses report t-values for the parameter estimates. Variable definitions are given in table 2A.3. The variables IPP3, POP, T, QUFO, QUJO, QUFB, QUCPP, QUCEP, PCEDC, PIF, and PIP are used as instruments in the estimation. The R^2 values suggest a good fit and the Durbin-Watson statistics either reject the presence of first-order autocorrelation or are inconclusive.

Apple production technologies have significantly changed in the years over which the model is estimated. Large areas of land became available to apple production due to irrigation, particularly in the Columbia-River area in the Northwest. Because of this, the West has replaced the East as the largest apple-producing region of the United States. New varieties have been adopted, and a shift to high-density orchards occurred.

These changes cannot be explained solely by changes in input and output prices and even if they could, hardly any data on input costs are available for the apple industry. To model these structural shifts in the data, dummy variables are employed in the estimation process. Next, we will describe our results and explain any adjustments that are made to the general model outlined in the previous section.

Northwest

The acreage equation includes a dummy for the years 1986-87, when Washington experienced an unusually large increase in bearing acreage. The allocation equation suggests that 66% of the increases in total production are allocated to fresh consumption and that an increase in the price premium paid for fresh apples increases fresh production significantly. Looking at the regional pricing equations, we can conclude that prices are more variable in the Northwest than in the other regions, as the multiplicative term is greater than one.

Southwest

The equation for the acreage includes a dummy variable to account for sudden increases that occurred in the acreage of apple production in the late 1980s in California. This increase might have been caused by the large increase in prices for fresh apples after 1986. California experienced in the 1980s an increased acreage planted to the then new variety Fuji. The alar crisis of the 1980s might be another factor explaining these structural shifts.

In comparison to the Northwest, a smaller share of the above average production is allocated to the market for fresh apples, and increases in the premium for fresh apples causes a statistically significant adjustment in the allocation to the fresh market. Prices for fresh apples are less variable than they are in other regions.

Central

A dummy variable for years after 1981 is included in the acreage equation. It marks the year when the trend of decreasing acreage in Michigan was reversed and when Michigan started planting heavily towards processing apples. At the same time we experience an increase in the average yield level. Industry experts indicated to us that at this time returns in the apple industry were quite favorable and encouraged replanting of older orchards. Many of the then newly planted orchards are of improved technology (higher density) and yield a larger crop.

For the yield equation, the relationship between prices and yields seemed to change in the last two years of the data. We control for this change by including a dummy variable for 1996-97. During these years, imports of processed apples increased substantially, where most of these additional imports originate in China. We experience for instance at the same time a sudden drop in the price for processed apples in the Northwest from 7.5 ¢/lb. to 4.1 ¢/lb. More years of data would be needed to measure a structural adjustment or to establish that this is a temporary aberration.

East

Due to the growing competition from western states, acreage has been steadily declining in the East. Changes in acreage depend significantly on price developments, much more so here than they do in other regions. About 17% of above average total production are allocated to the fresh market.

General Supply Component

In general, the estimates of the yield equation show that the Northwest has benefited more from technological progress in the apple industry than any other region. After accounting for market changes, average yields increased by 698 lb./acre/year in the Northwest, compared with 229 lb./acre/year in the Southwest, 250 lb./acre/year in the Central, and 113 lb./acre/year in the East.

The allocation equations in all regions show that if total production increases, a smaller than average share of total production is allocated to fresh utilization, i.e., the average share of fresh production in the Northwest is 73.2% and 66% of an increase in total production are marketed as fresh. For the Southwest the average fresh production share is 38.5%, for the Central it is 50.6%, and for the East it is 43.4%.

Net Imports

Turning to the net import equations it is found that the home price level is significant in the determination of net imports of both fresh and processed apples. The per-unit value of imports, on the other hand, is significant in the fresh market but not so in the processed market. Low quantities of home production increase net imports, i.e., increase imports and/or lower exports.[2] Net imports respond more to home production in the processing sector than they do in the fresh sector. Both imports for fresh apples and processing apples increase over time but imports in the processing sector are increasing at a faster absolute rate. In fact, net imports are negative for fresh apples and positive for processed apples so that our model predicts a decreasing trade surplus in the fresh apple market and an increasing trade deficit in the processed apple markets given recent price and home production levels.

The estimates indicate that imports of processed apples are much more responsive to changes in the home market than it is the case for the fresh market. Both the responsiveness to the U.S. price level and the responsiveness to the quantity of home production are larger.

Demand

The demand equations show that demand for fresh and processed apples is decreasing in prices and increasing in income. The income coefficient is larger in the demand for fresh apples than for processed apples.

Fresh oranges were used as the alternative fruits in the equation for fresh demand and orange juice as the alternative in the equation for processed demand. Other fruits such as fresh bananas, canned pears, and canned peaches were tested as additional or alternative substitutes but failed to improve the estimation. Fresh oranges serve as substitutes for fresh apples. However, orange juice serves a complement of processed apples. Since increased apple juice consumption is the primary cause for the increased consumption of processed apples in general, we conclude that orange juice measures a change in taste towards higher juice consumption, a result that is also found in Willet.

Elasticity Estimation

Elasticities are calculated by first evaluating the system at the means of the data. Then U.S. level prices for fresh apples and/or processed apples are shocked by a constant over a five-year period. The changed quantities in the market are simulated forward separately for the supply and demand side and the elasticities for each year are calculated using the changed quantity in the specific year after the initial shock. Their value is reported for a one-year lag and five-year lag. Given the structure of the model, the elasticities for the first year after an exogenous change in output price can only include yield and allocation changes, while at a five-year lag acreage might adjust as well. For the demand and net import equations the model is static, hence elasticities are the same for all years.

We report two types of elasticities. Table 2A1.4 gives partial elasticities that measure immediate quantity responses following a change in prices, for instance $\in_{QPFNW,PF}$ $= \partial \ln QPFNW / \partial \ln PF$ where QPPNW is held constant. Table 2A1.5 gives in addition elasticities for the overall production component of the model where fresh and processed production are allowed to adjust simultaneously, e.g., $E_{QPFNW,PF} = d \ln QPFNW / d \ln PF$. Total supply response elasticities are not reported for the demand and net import component because those do not include cross terms.

A nonparametric bootstrap method of 1000 iterations was used to determine the statistical significance of the elasticity estimates and asterisks mark the elasticities that are significant at the 0.1 level. To implement the bootstrap the system is first estimated and predicted values are calculated for the sample period. A matrix of residuals is formed for the entire system, and we randomly draw with replacement residuals from this matrix. Adding the series of resampled residuals to the respective series of predicted values, a new data set of random-error-adjusted predicted values is formed. The system is reestimated using these adjusted predicted values and this procedure is repeated 1000 times. Elasticities are calculated for each estimation and their statistical significance is determined (Efron; Schroeder).

Supply responses are inelastic to price changes in the short run. The technology of apple production allows only for slow adjustments because newly planted orchards take several years to come into full bearing and yields can only be adjusted to a very limited extent. Although technology constrains growers to a relatively inelastic response in total production, they can also adjust by reallocating production between the fresh and processing sector if relative prices change.

Looking at the cross elasticities of supply for the combined supply responses (table 2A.5), we can see that they are negative in all regions in the short run. The increase in average price due to the increase in the price for fresh or processed apples will induce an increase in yield and acreage. The change in relative prices will in addition cause the reallocation of crop to the utilization for which prices increase, and this reallocation outweighs the increase in total production in the short run. Turning to the long-run elasticities, the cross-price elasticity of processed production with respect to fresh price turns positive in the Northwest and Southwest, as now, given the increase in fresh price, total production will increase so much that both fresh and processed production increases.[3]

Own-price demand elasticities for fresh and processing apples are -0.37 and -0.70, respectively, and the overall demand elasticity with respect to an increase in average price is -0.55. The demand for apples responds relatively inelastically to changes in prices. The income elasticity is 1.2 for fresh apples and 2.6 for processed apples.

Hossain reports own price demand elasticities of -0.81 and -0.94 for fresh and processed apples respectively. For his model, this gives a total demand elasticity of about -0.86, a higher elasticity of demand than our result. His income elasticities are, on the other hand, much lower with values of 0.04 and 0.43 for fresh and processed apples. He calculates short-term supply elasticities of 0.08 and 0.12 for fresh and processed apples that are smaller than ours. However, his model allows only for direct reallocation effects.

Our income elasticities are more in line with results of Baumes and Conway who report income elasticities of 1.07 and 0.73 for fresh and processed apples, respectively. Their demand elasticities are -1.14 and -1.17 respectively, resulting in a total demand elasticity of -1.15.

Conclusion

Elasticity estimates are obtained for supply and demand responses to price changes in the markets for fresh and processed apples. The supply elasticities are estimated for four production regions, and differences in growers' ability to respond to market changes are evident in these estimates. The resulting elasticity estimates are useful in the estimation of regional impacts that result from changes in the technological or economic environment.

Notes

[1] List of filled in data: Acreage: Arizona (1984-88), Colorado (1984-92), New Mexico (1988-92), Utah (1984-92), Idaho (1984-92), Georgia (1988-89), Delaware (1985-92), Maryland (1984-92), Connecticut (1984-92), Maine (1984-92), Massachusetts (1984-92), New Hampshire (1984-92), Rhode Island (1984-92), Vermont (1984-92), Kentucky (1984-92), Illinois (1984-92), Indiana (1984-92), Iowa (1984-92), Kansas (1984-92), Minnesota (1984-92), Missouri (1984-92). Percentage of Fresh Production: Arizona (1978-88), Colorado (1975-76), New Mexico (1969-75,1980-86), Utah (1971), Georgia (1969-1997: replaced by regional mean), Delaware (1973-97: replaced by regional mean), Rhode Island (1969-97: replaced by regional mean), Arkansas (1969-97: replaced by regional mean), Kentucky (1969-76,1979-81), Tennessee (1969-70, 1972-1997: replaced by regional mean), Illinois (1975), Iowa (1969-73,1976,1978-97), Kansas (1974-76,1980,1989-97),

Minnesota (1971,1973-75,1979-1997). Fresh Prices: Arizona (1978-88), Colorado (1975-76), New Mexico (1969-75,1980-86), Utah (1971), South Carolina (1969-72,1980,1982), Georgia (1969-1997), Delaware (1973-97), Rhode Island (1969-97), Arkansas (1969-97), Kentucky (1969-76), Tennessee (1969-70, 1972-1997), Illinois (1975), Iowa (1969-73,1976,1978-97), Kansas (1974-76,1980,1989-97), Minnesota (1971,1973-75,1979-1997).

[2] The United States produces 4,733 mill. metric tons or 9% of worldwide apple production (FAO, Production Yearbook, 1996). Exports amount to 0.6 mill. metric tons or 12% of the 5.2 mill. metric tons exported worldwide (FAO, Trade Yearbook, 1996).

[3] One can check the supply elasticities with system (1) and (2). There we model the change in price resulting from a change in quantity using the flexibility, under the assumption that we can approximate $\partial MC^i / \partial Q^l$ by $\partial P^i / \partial Q^l$, $i, l =$ F, P. Employing the fact that the system of flexibilities equals the inverse of the system of elasticities, i.e.,

$$\begin{bmatrix} \partial \ln P^F / \partial \ln Q^F & \partial \ln P^F / \partial \ln Q^P \\ \partial \ln P^P / \partial \ln Q^F & \partial \ln P^P / \partial \ln Q^P \end{bmatrix} = \begin{bmatrix} \partial \ln Q^F / \partial \ln P^F & \partial \ln Q^F / \partial \ln P^P \\ \partial \ln Q^P / \partial \ln P^F & \partial \ln Q^P / \partial \ln P^P \end{bmatrix}^{-1},$$

the second-order conditions of profit maximization or cost minimization require that $\partial MC^F / \partial Q^F \cdot \partial MC^P / \partial Q^P - \partial MC^F / \partial Q^P \cdot \partial MC^P / \partial Q^F \geq 0$, which is equivalent to the restriction $\epsilon_{FF} \epsilon_{PP} - \epsilon_{FP} \epsilon_{PF} \geq 0$ on the elasticities, a restriction that holds for our system in all regions. Hence the supply system is stable in the sense that producers cannot increase profit by reallocating fruit from fresh to processed utilization.

Table 2A.1. **Production Regions, 1997** [a]

Region	States	Bearing Acreage (000 acres)	Total Production (mill. lb.)	Fresh Production (mill. lb.)	Average Price (c/lb.)	Fresh Price (c/lb.)	Processed Price (c/lb.)
Northwest	Washington, Oregon, Idaho	170.3	5270.0	3762.0	16.7	21.7	4.1
Southwest	Arizona, California, Colorado, Utah, New Mexico	50.5	1091.0	440.0	16.6	32.4	6.4
Central	Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, Tennessee, Wisconsin	92.6	1413.1	1050.1	13.2	20.3	7.3
East	Delaware, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia,	140.6	2627.0	574.9	13.5	24.9	8.3
U.S.		**454.0**	**10401.1**	**5827.1**	**15.4**	**23.0**	**6.4**

[a] Numbers might not add up due to rounding.

Table 2A.2. Estimation Results

<u>Supply Sector</u>		
Northwest		
$\Delta ABNW_t =$	$-0.124 + 20.540\ PANW3_{t-3}/IPP3_{t-3} + 11.000\ D867$ $(-0.059)\ (1.491)\ (8.951)$	$R^2 = 0.497$ $DW = 1.276$
$ABNW_t =$	$ABNW_{t-1} + \Delta ABNW_t$	
$YNW_t =$	$7.192 + 0.674\ PANW3_{t-1} + 0.698\ T$ $(2.054)\ (4.426)\ (8.805)$	$R^2 = 0.523$ $DW = 1.695$
$QPTNW_t =$	$ABNW_t * YNW_t$	
Southwest		
$\Delta ABSW_t =$	$-2.821 + 22.290\ PASW3_{t-3}/IPP3_{t-3} + 4.834\ D879$ $(-1.497)\ (1.521)\ (6.782)$	$R^2 = 0.471$ $DW = 2.312$
$ABSW_t =$	$ABSW_{t-1} + \Delta ABSW_t$	
$YSW_t =$	$-0.165 + 1.065\ PASW3_{t-1} + 0.229\ T$ $(-0.083)\ (8.818)\ (6.398)$	$R^2 = 0.513$ $DW = 2.400$
$QPTSW_t =$	$ABSW_t * YSW_t$	
Central		
$\Delta ABC_t =$	$-7.926 + 37.948\ PAC3_{t-3}/IPP3_{t-3} + 3.952\ D81$ $(-3.883)\ (2.883)\ (6.965)$	$R^2 = 0.433$ $DW = 1.324$
$ABC_t =$	$ABC_{t-1} + \Delta ABC_t$	
$YC_t =$	$9.906 + 0.050\ PAC3_{t-1} + 0.250\ T - 4.730\ D967$ $(3.227)\ (0.340)\ (3.907)\ (-5.026)$	$R^2 = 0.316$ $DW = 2.383$
$QPTC_t =$	$ABC_t * YC_t$	
East		
$\Delta ABE_t =$	$-11.659 + 79.046\ PAE3_{t-3}/IPP3_{t-3}$ $(-4.911)\ (4.231)$	$R^2 = 0.363$ $DW = 1.851$
$ABE_t =$	$ABE_{t-1} + \Delta ABE_t$	
$YE_t =$	$13.567 + 0.071\ PAE3_{t-1} + 0.113\ T$ $(10.405)\ (1.081)\ (4.087)$	$R^2 = 0.350$ $DW = 1.841$
$QPTE_t =$	$ABE_t * YE_t$	

Table 2A.2 (continued)

Allocation

Northwest

$QPFNW_t = -0.808 + 16.419\ (PFNW_t - PPNW_t) + 0.661\ QPTNW_t$ $R^2 = 0.975$
(-0.007) (2.033) (44.637) DW=2.437

$QPPNW_t = QPTNW_t - QPFNW_t$

Southwest

$QPFSW_t = -128.253 + 8.251\ (PFSW_t - PFSW_t) + 0.354\ QPTSW_t$ $R^2 = 0.878$
(-5.086) (5.414) (12.127) DW=1.931

$QPPSW_t = QPTSW_t - QPFSW_t$

Central

$QPFC_t = -357.647 + 28.488\ (PFC_t - PPC_t) + 0.493\ QPTC_t$ $R^2 = 0.693$
(-3.366) (6.960) (9.603) DW=2.372

$QPPC_t = QPTC_t - QPFC_t$

East

$QPFE_t = 242.384 + 34.544\ (PFE_t - PPE_t) + 0.173\ QPTE_t$ $R^2 = 0.627$
(2.336) (7.491) (4.652) DW=1.730

$QPPE_t = QPTE_t - QPFE_t$

Regional Price Determination

Northwest

$PFNW_t = -4.596 + 1.197\ PF_t$ $R^2 = 0.881$
(-3.125) (17.833) DW=1.794

$PPNW_t = -4.923 + 1.535\ PP_t$ $R^2 = 0.764$
(-5.376) (15.205) DW=1.557

$PANW_t = (QPFNW_t * PFNW_t + QPPNW_t * PPNW_t) / QPTNW_t$

Southwest

$PFSW_t = 15.260 + 0.460\ PF_t + 4.617\ D86$ $R^2 = 0.533$
(5.809) (4.123) (5.970) DW=2.133

$PPSW_t = -2.758 + 1.364\ PP_t$ $R^2 = 0.702$
(-2.673) (11.862) DW=1.931

$PASW_t = (QPFSW_t * PFSW_t + QPPSW_t * PPSW_t) / QPTSW_t$

Table 2A.2 (continued)

Central		
$PFC_t =$	$1.794 + 0.916\ PF_t$	$R^2 = 0.718$
	(0.875) (9.990)	DW=1.826
$PPC_t =$	$2.024 + 0.814\ PP_t$	$R^2 = 0.832$
	(3.414) (12.787)	DW=2.446
$PAC_t =$	$(QPFC_t * PFC_t + QPPC_t * PPC_t) / QPTC_t$	
East		
$PFE_t =$	$0.670 + 1.020\ PF_t$	$R^2 = 0.627$
	(0.238) (8.077)	DW=1.270
$PPE_t =$	$2.731 + 0.688\ PP_t$	$R^2 = 0.872$
	(6.398) (15.070)	DW=1.785
$PAE_t =$	$(QPFE_t * PFE_t + QPPE_t * PPE_t) / QPTE_t$	
Aggregation to U.S. Production		
$QPF_t =$	$QPFNW_t + QPFSW_t + QPFC_t + QPFE_t$	
$QPP_t =$	$QPPNW_t + QPPSW_t + QPPC_t + QPPE_t$	
Utilization		
$QUF_t =$	$QPF_t/POP_t - NIF_t/POP_t$	
$QUP_t =$	$QPP_t/POP_t - NIP_t/POP_t$	
Net Imports		
$NIF_t =$	$3024.12 - 31.320\ PF_t - 579.324\ PIF_t - 0.632\ QPF_t + 23.779\ T$	$R^2 = 0.873$
	(11.346) (-5.540) (-2.026) (-11.900) (3.688)	DW=0.941
$NIP_t =$	$2855.47 - 100.344\ PP_t - 23.190\ PIP_t - 0.758\ QPP_t + 172.664\ T$	$R^2 = 0.870$
	(4.803) (-2.369) (-0.094) (-3.827) (9.229)	DW=1.424
Demand		
$PF_t =$	$24.401 - 3.202\ QUF_t - 0.059\ QUFO_t + 0.021\ PCEDC_t - 0.941\ T$	$R^2 = 0.650$
	(2.281) (-7.947) (-0.514) (4.189) (-4.458)	DW=0.920
$PP_t =$	$-8.667 - 0.540\ QUP_t + 0.507\ QUJO_t + 0.009\ PCEDC_t - 0.316\ T$	$R^2 = 0.478$
	(-1.155) (-5.989) (2.213) (3.237) (-2.509)	DW=1.747

Table 2A.3. Definition of the Variables

$ABNW_t$	Bearing acreage in Northwest in year t	(000 acres)
$ABSW_t$	Bearing acreage in Southwest in year t	(000 acres)
ABC_t	Bearing acreage in Central in year t	(000 acres)
ABE_t	Bearing acreage in East in year t	(000 acres)
$\Delta ABNW_t$	Change in bearing acreage in Northwest from year t-1 to year t	(000 acres)
$\Delta ABSW_t$	Change in bearing acreage in Southwest from year t-1 to year t	(000 acres)
ΔABC_t	Change in bearing acreage in Central from year t-1 to year t	(000 acres)
ΔABE_t	Change in bearing acreage in East in year t-1 to year t	(000 acres)
YNW_t	Yield/acre in Northwest in year t	(000 lb./acre)
YSW_t	Yield/acre in Southwest in year t	(000 lb./acre)
YC_t	Yield/acre in Central in year t	(000 lb./acre)
YE_t	Yield/acre in East in year t	(000 lb./acre)
$QPTNW_t$	Total production in Northwest in year t	(mill. lb.)
$QPTSW_t$	Total production in Southwest in year t	(mill. lb.)
$QPTC_t$	Total production in Central in year t	(mill. lb.)
$QPTE_t$	Total production in East in year t	(mill. lb.)
$QPFNW_t$	Quantity marketed as fresh in Northwest in year t	(mill. lb.)
$QPFSW_t$	Quantity marketed as fresh in Southwest in year t	(mill. lb.)
$QPFC_t$	Quantity marketed as fresh in Central in year t	(mill. lb.)
$QPFE_t$	Quantity marketed as fresh in East in year t	(mill. lb.)
$QPPNW_t$	Quantity marketed as processed in Northwest in year t	(mill. lb.)
$QPPSW_t$	Quantity marketed as processed in Southwest in year t	(mill. lb.)
$QPPC_t$	Quantity marketed as processed in Central in year t	(mill. lb.)
$QPPE_t$	Quantity marketed as processed in East in year t	(mill. lb.)
QPF_t	U.S. fresh production in year t	(mill. lb.)
QPP_t	U.S. processed production in year t	(mill. lb.)
$PFNW_t$	Price received by growers for fresh apples in Northwest in year t	(¢/lb.)
$PPNW_t$	Price received by growers for processed apples in Northwest in year t	(¢/lb.)
$PANW_t$	Average price received by growers in Northwest in year t	(¢/lb.)
$PANW3_t$	Three-year average of $PANW_t$ based on periods t-2, t-1, t	(¢/lb.)
$PFSW_t$	Price received by growers for fresh apples in Southwest in year t	(¢/lb.)
$PPSW_t$	Price received by growers for processed apples in Southwest in year t	(¢/lb.)
$PASW_t$	Average price received by growers in Southwest in year t	(¢/lb.)
$PASW3_t$	Three-year average of $PASW_t$ based on periods t-2, t-1, t	(¢/lb.)

Table 2A.3 (continued)

PFC_t	Price received by growers for fresh apples in Central in year t	(¢/lb.)
PPC_t	Price received by growers for processed apples in Central in year t	(¢/lb.)
PAC_t	Average price received by growers in Central in year t	(¢/lb.)
$PAC3_t$	Three-year average of PAC_t based on periods t-2, t-1, t	(¢/lb.)
PFE_t	Price received by growers for fresh apples in East in year t	(¢/lb.)
PPE_t	Price received by growers for processed apples in East in year t	(¢/lb.)
PAE_t	Average price received by growers in East in year t	(¢/lb.)
$PAE3_t$	Three-year average of PAE_t based on periods t-2, t-1, t	(¢/lb.)
PF_t	Price received by growers for fresh apples in year t	(¢/lb.)
PP_t	Price received by growers for processed apples in year t	(¢/lb.)
IPP_t	Index of prices paid by farmers in year t	(1977=100)
$IPP3_t$	Three-year moving average (t,...,t-2) of IPP_t	
T	Time index, incremented by 1 each year (1971=1)	
D81	Dummy variable (0 before 1981, 0 otherwise)	
D86	Dummy variable (0 before 1986, 1 otherwise)	
D867	Dummy variable (1 in 1986-87, 0 otherwise)	
D879	Dummy variable (1 in 1987-89, 0 otherwise)	
D967	Dummy variable (1 in 1996-97, 0 otherwise)	
NIF_t	Net imports of fresh apples in year t	(mill. lb.)
NIP_t	Net imports of processing apples (fresh fruit equivalent) in year t	(mill. lb.)
PIF_t	Unit value of fresh net imports in year t	(¢/lb.)
PIP_t	Unit value of juice net imports (fresh fruit equivalent) in year t	(¢/lb.)
POP_t	U.S. Population in year t	(mill.)
QUF_t	Per-capita utilization of fresh apples with net imports in year t	(lb./capita/year)
QUP_t	Per-capita utilization of processed apples with net imports in year t	(lb./capita/year)
$QUFB_t$	Per-capita consumption of fresh bananas in year t	(lb./capita/year)
$QUFO_t$	Per-capita consumption of fresh oranges in year t	(lb./capita/year)
$QUCPP_t$	Per-capita consumption of canned peaches in year t	(lb./capita/year)
$QUCEP_t$	Per-capita consumption of canned pears in year t	(lb./capita/year)
$QUJO_t$	Per-capita consumption of orange juice in year t	(lb./capita/year)
$PCEDC_t$	Private consumption expenditure per person on food in year t	($)

(all prices, including IPP_t, are deflated by the GDP deflator, 1992=100)

Table 2A.4. Partial Elasticities (calculated at means)[a]

		Short Run (Year 1)	Long Run (Year 5)
Northwest			
Fresh Production	$\epsilon_{QPFNW.PF}$	0.313	0.622
	$\epsilon_{QPFNW.PP}$	-0.063	-0.025
Processed Production	$\epsilon_{QPPNW.PF}$	0.504	1.139
	$\epsilon_{QPPNW.PP}$	0.095	0.261
Southwest			
Fresh Production	$\epsilon_{QPFSW.PF}$	0.359*	0.518*
	$\epsilon_{QPFSW.PP}$	-0.237*	-0.157
Processed Production	$\epsilon_{QPPSW.PF}$	0.110	0.259
	$\epsilon_{QPPSW.PP}$	0.197*	0.494*
Central			
Fresh Production	$\epsilon_{QPFC.PF}$	0.873*	1.018*
	$\epsilon_{QPFC.PP}$	-0.288*	-0.281*
Processed Production	$\epsilon_{QPPC.PF}$	0.033*	0.197*
	$\epsilon_{QPPC.PP}$	0.004*	0.054*
East			
Fresh Production	$\epsilon_{QPFE.PF}$	0.639*	0.717*
	$\epsilon_{QPFE.PP}$	-0.162*	-0.159*
Processed Production	$\epsilon_{QPPE.PF}$	0.026*	0.225*
	$\epsilon_{QPPE.PP}$	0.008*	0.071*
Consumption			
	$\epsilon_{QPF.PF}$	-0.374	-0.374
	$\epsilon_{QPP.PP}$	-0.701	-0.701
	$\epsilon_{QPT.PA}$	-0.554	-0.554
	$\epsilon_{QPF.PCEDC}$	1.195	1.195
	$\epsilon_{QPP.PCEDC}$	2.591	2.591
	$\epsilon_{QPT.PCEDC}$	1.961	1.961
Import			
	$\epsilon_{NIF.PF}$	-0.609	-0.609
	$\epsilon_{NIP.PP}$	-0.791	-0.791
	$\epsilon_{NIF.QPF}$	-3.276	-3.276
	$\epsilon_{NIP.QPP}$	-3.193	-3.193

[a] The asterisk marks significance at the 10% level.

Table 2A.5. Total Supply Response Elasticities (calculated at means)[a]

		Short Run (Year 1)	Long Run (Year 5)
Northwest			
Fresh Production	$E_{QPFNW.PF}$	0.306	0.623
	$E_{QPFNW.PP}$	-0.059	-0.006
Processed Production	$E_{QPPNW.PF}$	-0.220	0.237*
	$E_{QPPNW.PP}$	0.229*	0.272*
Southwest			
Fresh Production	$E_{QPFSW.PF}$	0.346*	0.540*
	$E_{QPFSW.PP}$	-0.225*	-0.065
Processed Production	$E_{QPPSW.PF}$	-0.055*	0.215*
	$E_{QPPSW.PP}$	0.279*	0.452*
Central			
Fresh Production	$E_{QPFC.PF}$	0.868*	0.981*
	$E_{QPFC.PP}$	-0.288*	-0.269*
Processed Production	$E_{QPPC.PF}$	-0.831	-0.668
	$E_{QPPC.PP}$	0.291	0.295
East			
Fresh Production	$E_{QPFE.PF}$	0.638*	0.708*
	$E_{QPFE.PP}$	-0.162*	-0.157*
Processed Production	$E_{QPPE.PF}$	-0.467	-0.288
	$E_{QPPE.PP}$	0.133	0.180

[a] The asterisks marks significance at the 10% level.

CHAPTER 3. CAPTURING EXPERTS' UNCERTAINTY IN WELFARE ANALYSIS: AN APPLICATION TO ORGANOPHOSPHATE USE REGULATION IN U.S. APPLE PRODUCTION

A paper to be submitted to the American Journal of Agricultural Economics

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Abstract

Many regulatory actions require ex-ante assessments of benefits and costs although the impacts of these actions are uncertain and information about the statistical properties of impacts is needed for welfare analysis. This paper proposes a method for deriving distributions of welfare changes. Issues of impact uncertainty in welfare assessments are explained, and it is shown how probability distributions over policy impacts can be estimated using a collection of dispersed expert opinions. Welfare outcomes are ordered using a nonparametric test for stochastic ordering of probability distributions. The methods are demonstrated for the case of organophosphate use regulation in U.S. apple production.

Introduction

Many regulatory actions require the assessment of benefits and costs of policies although the outcomes of those policies are uncertain. Then information about the statistical properties of changes in the economic environment is sought for alternative policies. Knowledge of first moments of uncertain supply and demand shifts is not sufficient in welfare analysis, even if the goal is only to assess the expected change in economic surplus using linear shocks and linear supply and demand functions. Welfare analysis involves the study of areas in price-quantity space and entails the integration over the distribution of shift parameters. Even if supply and demand curves are linear in the shocks of interest, the welfare areas they define are not. Hence welfare analysis requires the knowledge of second and possibly higher moments.

Because of a lack of historical or experimental data, future scenarios are frequently based on expert opinions. However, policy makers, regulatory agencies, and experts themselves are often concerned about the uncertainty that underlies these expert estimates. In this study, a method of dealing with experts' uncertainty is proposed. It is shown how ex-ante welfare analysis can include uncertainty over experts' estimates and how it can stochastically order random outcomes of policies under consideration. The procedure is demonstrated using the example of regulating organophosphate insecticides in U.S. apple production.

The paper proceeds with a discussion of the implications of impact uncertainty on welfare analysis. It is shown how expert opinion can be gathered in a partial probabilistic specification and how opinions from several experts can be combined. A description of the application and the economic model used to estimate the welfare impact of random technology shocks is followed by a discussion of the data. Welfare impacts are presented as estimated distributions of economic surplus changes, and it is demonstrated how those distributions can be ordered using a nonparametric test for stochastic orderings. The paper concludes with a discussion of advantages and disadvantages of the proposed method.

Impact Uncertainty in Welfare Assessments

Throughout this paper, we use economic surplus as a welfare measure which is defined as the sum of consumer and producer surplus and the usual caveats regarding their appropriateness as welfare measures apply. Formally, welfare is specified as $W = \int_0^{Q^0} Z(Q)\,dQ$ where $Z(Q)$ is the inverse excess demand function and where Q^0 is the market-clearing quantity such that $Z(Q^0) = 0$.[3] Suppose that a random shock θ occurs to the excess demand function. The new market clearing occurs at $\hat{Q} = \{Q : Z(Q) + \theta = 0\}$ or $\hat{Q} = Z^{-1}(-\theta)$ and the expected change in welfare[4] is defined as

$$E_\theta[dW] = E\left[\int_0^{\hat{Q}} [Z(Q) + \theta]dQ\right] - \int_0^{Q^0} Z(Q)dQ$$

To simplify the exposition, let $Z(Q) = a - bQ$ where a and b are positive constants, so that $\hat{Q} = (a + \theta) / b$ and the expected welfare change solves as $E_\theta[dW] = E_\theta\left[2a\theta + \theta^2\right]/2b$, which is clearly a function of the second moment of θ. If shocks or the excess demand function are nonlinear, higher moments will be needed for the welfare analysis. This would also be the case if the policy-maker's utility function is nonlinear in welfare changes, for instance if the policy-maker expresses risk aversion.

If the objective is to compare the welfare properties of two policies that induce random shocks to the supply or demand curve, it can be shown that an ordering of the shocks in a first-degree stochastic dominance (FSD) sense will suffice to order the distributions of welfare changes for all policy makers, as long as they seek to maximize expected utility and as long as their utility function increases in expected welfare changes. That is if θ_1 *FSD* θ_2, then the distribution of welfare changes induced by θ_1 will be preferred to the welfare changes induced by θ_2.[5] However, since economic surplus is a convex function of any shock to the excess demand function, the result cannot be extended to the case of second-degree stochastic dominance (SSD).

This means that an ordering of the shocks to the excess supply curve in the FSD sense is sufficient for a welfare ordering but that this does not hold true if shocks can only be ordered in the SSD sense. Then it is necessary to compare the distributions of induced welfare changes directly. Distributions can be ordered in the FSD or SSD sense using a nonparametric test for stochastic orderings (Anderson) whose implementation is illustrated later in this paper.

This discussion illustrates that the knowledge of the distributional properties of θ is needed for welfare analysis, and we turn next to the issue of how to obtain such information.

Combining Probabilistic Expert Opinion

Information about the unknown θ that follows the unknown random distribution $G(\theta)$ is sought. The goal is to find an estimate of G using expert opinion so that policies can be compared by using ex-ante welfare measures. G is unknown and any estimate of G will be a random function itself.

Experts i = 1, 2, . . . , N are asked to give their probability assessment for θ, and we denote expert i's opinion over θ by θ_i. To simplify the experts' task, estimates of probabilities for a small number of intervals of θ are collected rather than a complete estimate of $G(\theta)$. For this purpose the range of θ is partitioned into K intervals with endpoints $-\infty \leq a_0 < ... < a_K \leq \infty$, which is equivalent to collecting information about a discretized version of θ denoted by θ^k such that $\theta^k = j$ if $\theta \in (a_{j-1}, a_j]$. The information obtained from each expert can be described by

$$H_i = \{(g_{i1}, g_{i2}, \ldots, g_{iK}) : g_{ij} = \Pr(\theta_i^k = j); j = 1, \ldots, K; \sum_j g_{ij} = 1\},$$

i = 1, ... , N, where g_{ik} is expert i's estimate of the probability that θ is in the k-th interval. Note that θ^k is a complete partition of the range of θ and that $\sum_{j=1}^{K} g_{ij} = 1$ must hold.

The Bayesian approach has proven useful in problems of aggregating probabilistic information from different sources (Dorfman). We employ Bayes paradigm in a Suprabayesian framework, where a Suprabayesian S collects and summarizes opinions coming from several experts. He himself supplies an estimate of $G(\theta)$ which will serve as the Bayesian prior and is denoted by $\rho(\theta)$.

We can combine the probability estimates using Bayesian updating. Treating S's opinion as the prior and the expert's information H_i as data, Bayes' formula yields the posterior

$$p_i^*(\theta \mid \mathrm{S}, H_i) = \frac{\rho(\theta)\ \Pr(H_i|\theta)}{\int \Pr(H_i|\theta)\, \rho(\theta)\, d\theta} \propto \rho(\theta) \Pr(H_i|\theta)$$

where $\Pr(H_i|\theta)$ is a K-dimensional probability measure. To combine the information coming from several experts, the assumption of conditional independence between experts is made, i.e., $\{H_1 \mid \theta\}, \{H_2 \mid \theta\}, \ldots, \{H_N \mid \theta\}$ are assumed to be independent. This assumption is commonly made in expert opinion analyses and means that the dependence in experts' opinions stems from θ and only from θ (Genest and Schervish). Then the full posterior can be calculated as

$$p^*(\theta \mid \mathrm{S}, H_1, H_2, \ldots, H_N) \propto \rho(\theta) \prod_{i=1}^{N} \Pr(H_i \mid \theta). \tag{1}$$

The problem is to specify $\Pr(H_i|\theta)$, and we apply a result derived by West and also West and Crosse. Suppose S holds some joint prior over $\{\theta, H_i\}$. As it would be very difficult to specify this prior completely, assume that S specifies her joint prior only partially through her prior over θ, $\rho(\theta)$, her expectation of the i-th expert's opinion,

$E[H_i] = E[(g_{i1},\ldots,g_{iK})] = (\mu_1,\ldots,\mu_K) = \mu$, and an estimate of correlation between her assessment $\rho(\theta)$ and the expert's assessment H_i. West's result (Theorem 1, p. 554) applies and the posterior can be calculated as

$$p_i^*(\theta \mid \text{S}, H_i) = \rho(\theta) + \sum_{j=1}^{K} \pi(\theta \mid \theta_i^k = j)(g_{ij} - \mu_j) \tag{2}$$

where $\pi(\theta \mid \theta_i^k = j) = p_i^*(\theta \mid g_{ij} = 1)$. Thus $\pi(\theta \mid \theta_i^k = j)$ is the S's posterior, were he to learn that the expert i believed $\theta_i^k = j$ with probability 1. This conditional probability is calculated consistent with the information available for the joint distribution over $\{\theta, H_i\}$, i.e., it shows the specified correlation between the two random variables and is consistent with the marginals μ and $\rho(\theta)$. As a result $\rho(\theta) = \sum_j \pi(\theta \mid \theta_i^k = j)\,\mu_j$ and the posterior results as

$$p_i^*(\theta \mid \text{S}, H_i) = \sum_{j=1}^{K} \pi(\theta \mid \theta_i^k = j)\, g_{ij}\,. \tag{3}$$

The posterior according to (2) or (3) is a linear combination of the prior and a weighted sum of the deviations between the expert's opinion and S's expectation of the expert opinion. It has to be emphasized that the expert opinion over the entire partition of θ^k will enter the calculation of the posterior for each point of θ.

The weights in the sum are formed by the conditional distribution of $\theta \mid \theta_i^k = j$. For a correlation close to zero, $\pi(\theta \mid \theta_i^k = j)$ will resemble $\rho(\theta)$ for all θ_i^k and the posterior will favor the prior over the expert opinion. As the correlation increases, $\pi(\theta \mid \theta_i^k = j)$ will deviate more from the prior and the expert opinion receives a large weight at points where

θ is likely given the expert's assessment on θ_i^k and a low weight if θ's conditional probability is low. In this study, it is supposed that θ and H_i are positively correlated and higher weights are given to the deviation in probability estimates for intervals of θ_i^k close to θ. If we would choose a negative correlation, more weight would be given to the expert opinion over θ_i^k far from θ. Appendix 3A offers a more detailed discussion of how one could interpret $\pi(\theta \mid \theta_i^k = j)$ and the correlation structure.

Using the rules for conditional probabilities, equation (3) can be rewritten in a more suitable form for the calculations as

$$p_i^*(\theta \mid \mathrm{S}, H_i) = \rho(\theta) \sum_{j=1}^{K} \frac{\pi(\theta_i^k = j \mid \theta)}{\mu_j} g_{ij} \,. \tag{4}$$

Combining equations (1) and (4) and applying the law of conditional probabilities the posterior for combining several expert opinions can be calculated as

$$\mathrm{p}^*(\theta \mid \mathrm{S}, H_1, H_2, ..., H_N) \propto \rho(\theta) \left[\prod_{i=1}^{N} \left(\sum_{j=1}^{K} \frac{\pi(\theta_i^k = j \mid \theta)}{\mu_j} g_{ij} \right) \right] \tag{5}$$

This is the formula used to derive the posterior from a collection of expert opinions. As we use the same μ and the same $\pi(\theta_i^k = j \mid \theta)$ for each expert i, all experts but S are treated identically. It would be straightforward to extend equation (5) to allow for an asymmetric treatment of the individual experts. Computational issues of implementing (5) are explained together with our data subsequently to the discussion of our case study to which we turn now.

An Application to Organophosphate Regulation in U.S. Apple Production

Using the context of a possible ban on organophosphate insecticides in U.S. apple production, it is shown how probability distributions over shocks to a market system can be estimated using expert opinion surveys and how these distributions can be used in ex-ante welfare analysis. Economic impacts of banning one organophosphate, azinphos-methyl (APM), and of banning the whole group of organophosphates (OPs) are estimated. The following paragraphs explain our application, and outline the economic model used for the welfare analysis.

Case Description

OPs are a group of neuroactive insecticides that are applied to more than 98% of the apple growing acreage in the United States (USDA. NASS/ERS). The Food Quality Protection Act (FQPA) of 1996 has brought new attention to the use of OPs in the Unites States and it is expected that in the near future strong limitations will be imposed on the use of OPs. This is because FQPA mandates risk assessments of pesticides by mode of toxic action instead of on a pesticide by pesticide basis and because it demands a higher level of risk protection for infants and children. A general loss of OPs is perceived as a major problem in the $1.7 bill. U.S. apple industry, as growers would lose control over many key insect pests. With 86% of U.S. apple acreage treated, APM is the most widely used OP (USDA. NASS/ERS). APM is an OP of particularly high toxicity and is one of the five highest ranking OPs posing risk to children according to the Environmental Working Group report by Wiles, Davies, and Campbell.

To limit the risk coming from OPs, it has been suggested to restrict the use of pesticides that pose the highest risk. In this way it is hoped to leave growers with substitute pesticides and thereby to limit the cost of the policy. However, a consumer study has shown that consumers are willing to pay a premium to avoid OPs but that the premium is negligible for avoiding APM only (Roosen et al.). Hence, we compare the welfare costs of removing

APM alone versus removing all OPs where a positive willingness to pay (WTP) shifts the demand function in the case of removing all OPs. Results show that depending on the size of the shift in the demand function, a cancellation of OPs could be the preferred option in terms of expected economic surplus changes.

Market Model of a Pesticide Ban in Apple Production

In apple production, pesticides are mainly used to preserve quality while protection against yield losses is generally a secondary consideration. Loss of quality is therefore an important consideration in this analysis. Apple production orchards are modeled as joint-product firms, producing apples for the fresh and processing market where the fresh market pays a considerable premium. A deterioration of quality is modeled as a decrease in the share of fruit allocated to the fresh market. The marginal welfare analysis suggested by Lichtenberg, Parker, and Zilberman is extended to this multiproduct analysis. In this framework, supply and/or demand functions are assumed to undergo parallel shifts given changes of the production technology, and flexibility estimates are used to calculate price and quantity changes. Marginal-cost impacts can be differentiated by region, and grower groups that are affected by the pesticide ban can be distinguished from those that will only be affected through market changes.

The market model is one of partial equilibrium, and growers are arranged into $j=1,\ldots, J$ groups that distinguish themselves in the way that their marginal cost function is impacted by the loss of a pesticide. Specifically, producers are grouped into sets of users and non-users of a pesticide in four geographical production regions: Northwest, Southwest, Central, and East. The cancellation of a pesticide presents a change in the technology available to growers, and the shift in technology is parameterized by λ and if growers do not use the pesticide, their technology is independent of λ. We order the groups such that j=1,..., t identify the producers that are affected by a change in λ, i.e. in our case the users of a pesticide to be banned, and j=t+1,..., J, denote the producers groups that are not affected by a ban. Denoting prices by P and quantities by Q, with subscript j identifying regions and superscript F and P signifying fresh and processed, respectively, the partial equilibrium can be described as:

Supply User:	$P_j^i = MC_j^i(Q_j^F, Q_j^P; \lambda)$,	$i = F, P; j = 1,...,t$	(6.1)
Supply Non-User:	$P_j^i = MC_j^i(Q_j^F, Q_j^P)$,	$i = F, P; j = t+1,..., J$	(6.2)
Regional Pricing:	$P_j^i = h_j^i(P^i)$,	$i = F, P; j = 1,..., J$	(6.3)
Demand:	$D^i(Q_d^i; \lambda) = P^i$,	$i = F, P$	(6.4)
Net Imports:	$Q_M^i = M^i(P^i, \sum_j Q_j^i)$,	$i = F, P$	(6.5)
Market Clearing:	$\sum_{j=1}^J Q_j^i + Q_M^i = Q_d^i$,	$i = F, P$	(6.6)

Equation (6.1) is the supply function for pesticide users and equation (6.2) is the supply function for non-users. The marginal cost functions (MC) depend on production to the fresh and processing sector to capture the joint-product character of the technology. Users and non-users produce at a level such that their level of marginal costs equals price both in the fresh and processing market. Equation (6.4) presents the inverse demand function (D) for fresh or processed apples. Demand is modeled at the U.S. level and P^i is the U.S. level price. The demand functions depend also on λ and a change in production technology can change consumers' preferences for the good. The regional supply functions are linked to the U.S. demand via regional pricing equations presented by $h_j^i(P^i)$ in equation (6.3). Equation (6.5) models net imports (Q_M^i) and the last equation (6.6) poses the market clearing conditions.

Totally differentiating this system, we can derive the impact of a change in technology (the loss of a pesticide) which is parameterized as a shift in λ.

$$f_j^{FF}\frac{P_j^F}{Q_j^F}dQ_j^F + f_j^{FP}\frac{P_j^F}{Q_j^P}dQ_j^P - dP_j^F = -\frac{\partial MC_j^F}{\partial \lambda}d\lambda \qquad j=1,\dots,t \quad (7.1a)$$

$$f_j^{PF}\frac{P_j^P}{Q_j^F}dQ_j^F + f_j^{PP}\frac{P_j^P}{Q_j^P}dQ_j^P - dP_j^P = -\frac{\partial MC_j^P}{\partial \lambda}d\lambda \qquad j=1,\dots,t \quad (7.1b)$$

$$f_j^{FF}\frac{P_j^F}{Q_j^F}dQ_j^F + f_j^{FP}\frac{P_j^F}{Q_j^P}dQ_j^P - dP_j^F = 0 \qquad j=t+1,\dots,J \quad (7.2a)$$

$$f_j^{PF}\frac{P_j^P}{Q_j^F}dQ_j^F + f_j^{PP}\frac{P_j^P}{Q_j^P}dQ_j^P - dP_j^P = 0 \qquad j=t+1,\dots,J \quad (7.2b)$$

$$dP_j^i - \frac{\partial h_j^i}{\partial P^i}dP^i = 0 \qquad i=F,P; j=1,\dots,J \quad (7.3)$$

$$f_d^{ii}\frac{P^i}{Q_d^i}dQ_d^i - dP^i = -\frac{\partial P^i}{\partial \lambda}d\lambda \qquad i=F,P \quad (7.4)$$

$$dQ_M^i - e_{MP}^i\frac{Q_M^i}{P^i}dP^i - e_{MQ}^i\frac{Q_M^i}{\left(\sum_j Q_j^i\right)}d\left(\sum_{j=1}^{J}Q_j^i\right) = 0 \qquad i=F,P \quad (7.5)$$

$$dQ_1^i + \cdots + dQ_J^i + dQ_M^i - dQ_d^i = 0 \qquad i=F,P \quad (7.6)$$

Expression f_j^{KL} denotes the flexibility of the price of good K with respect to the quantity of good L, where j indexes the region. The flexibility is a demand flexibility if j=d. For net imports e_{MP}^i and e_{MQ}^i indicates the elasticity of net imports with respect to U.S. price level and U.S. production for the respective market *i*. System (7) is linear in quantity and price changes, and can be solved by inversion.

Welfare Analysis

Using these solutions, consumer and producer surpluses can be calculated assuming that the ban induced shifts in the supply and demand curves are linear. We calculate producer and consumer surplus changes in the respective markets as the change in the area behind the supply or demand curve.

Calculating Marginal Cost Changes

To solve (7), an estimate of the change in marginal cost for producer group j is needed. A grower chooses the profit-maximizing level of production of apples for the fresh and processed market using his technology described by the cost function $C_j(Q_j^F, Q_j^P; \lambda)$. As described in (6.1) and (6.2), she will choose the level of production that equates the marginal cost of production for the fresh and processed market with the respective price. The problem is isomorphic to selecting the optimal level of yield, Y_j, and the optimal share of fruit going to the fresh market, α_j, as to

$$\max_{\alpha_j, Y_j} \pi_j(Y_j, \alpha_j; \lambda) = \left(\alpha_j P_j^F + (1-\alpha_j)P_j^P\right)Y_j - \Psi_j(Y_j, \alpha_j; \lambda)$$

where $\Psi_j(\cdot)$ is the alternative cost function specification that arises from the same technology as $C_j(Q_j^F, Q_j^P; \lambda)$. It is assumed to be convex in Y_j and α_j. The first-order conditions can be stated as

$$\Psi_{j,Y}(Y_j, \alpha_j, \lambda) = \alpha_j P_j^{\,F} + (1-\alpha_j)P_j^P$$
$$\Psi_{j,\alpha}(Y_j, \alpha_j, \lambda) = (P_j^F - P_j^P)Y_j$$

where second subscripts on Ψ_j denote first derivatives. This system of equations can be solved for

$$P_j^F = MC_j^F(Q_j^P, Q_j^P, \lambda) = \Psi_{j,Y} + (1-\alpha_j)\Psi_{j,\alpha}/Y_j \qquad (8.1)$$
$$P_j^P = MC_j^P(Q_j^P, Q_j^P, \lambda) = \Psi_{j,Y} - \alpha_j \Psi_{j,\alpha}/Y_j. \qquad (8.2)$$

Following Lichtenberg, Parker, and Zilberman, we approximate locally marginal costs of yield and fresh share by their average costs, i.e., $\Psi_{j,Y} = W_j / Y_j$ and $\Psi_{j,\alpha} / Y_j = P_j^F - P_j^P$, where the parameter W_j denotes the per acre cost. Implementing these approximations in (8.1) and (8.2), the change in marginal cost for fresh and processing production in the j-th region can be derived by taking the total differential with respect to W_j, Y_j, and α_j, and results as

$$\left[dW_j / Y_j - (\alpha_j P_j^F + (1-\alpha_j) P_j^P)\, dY_j / Y_j \;-\; (P_j^F - P_j^P)\; d\alpha_j\right] / \left(1 + 0.5\; dY_j / Y_j\right) \quad (9)$$

This is the equation used to estimate the change in marginal cost in region j given experts' estimates of changes in cost, yield, and fresh-market share.

Data and Computational Methods

Data

To estimate welfare impacts, (7) requires estimates of current prices and quantities in the market, flexibilities, demand shifts, and marginal cost impacts. Prices and quantities are obtained from USDA statistical publications and impacts were based on averages for 1994-1996 data. Summaries are provided in table 1 along with the percentage of acres treated by APM or NAI in each region given in table 2. Elasticity estimates are obtained in an econometric estimation of the U.S. apple market, and have been estimated for short-term (year 1) and long-term (year 5) impacts (Appendix 2A). Demand shift estimates are inferred from a consumer study (Roosen et al.), where it is found that consumers are willing to pay a premium for apples not treated by all OPs whereas the premium is almost negligible if only APM is removed. The demand function is shocked in the case of banning all OPs by $dP^i / d\lambda \sim N(\tau, 0.004)$, $i = F, P$, where τ is set to be 0%, 1.25%, or 2.5% of the market price for fresh and processing apples. The case τ =0% was chosen to estimate the impact if demand shifts are ignored, as it is often the case in studies of pesticide cancellations.[6]

Estimates of marginal cost impacts were obtained via an expert opinion survey and the survey instrument is included as Appendix 3B. The survey asked experts for their best probability estimates over intervals for changes in cost of production, yield, and fresh market share for the instance of a ban on APM and a ban on all OPs. The intervals are defined as in table 3. Experts were asked to estimate impacts for the year following a pesticide ban (short run) and the impact five years after the ban (long run).

The survey was sent to 52 experts who are entomologists working in extension, research, and industry. They were identified by the Suprabayesian S who is in charge of conducting a U.S. Department of Agriculture supported national study of impacts resulting from a loss of OPs in apple production. For the purpose of the survey, the United States were divided into three growing regions: East, Central and West, and 12, 4, and 14 valid questionnaires were returned for the respective regions.[7] The data supplied by the experts is shown in tables 4-15. Tables 4-6 give the short-run estimates for a ban on APM, tables 7-9 for a ban on OPs. Tables 10-15 continue with the long-run estimates. Expert estimates for the East are denoted by E1, E2, ..., for the Central by C1, C2, ..., and for the West by W1, W2, ... Not all experts replied to all questions which is the reason for some rows being blank in these tables.

In general, it appears that experts feel much more uncertain about the implications of a total ban on all OPs in the short run and in the long run, while their uncertainty about estimates of APM cancellation impacts increases when going from short run to long run.

In tables 4-15, the prior is given at the top of each category. It was formed using the probability estimations of the Suprabayesian who supplied the prior in the same discrete form as the experts for all three regions, i.e. as probabilities over intervals $\rho^k = (\rho_1, \rho_2, \ldots, \rho_K)$ where $\rho_j = \int_{a_{j-1}}^{a_j} \rho(\theta) d\theta$. However, for computational reasons, his prior was smoothed out to give a non-zero probability to every interval that received a positive probability by at least one expert.[8]

Computation

The posterior is set equal zero for intervals that received zero probability from all experts including S. We choose to modify the supplied expert opinion for all other intervals by giving some positive probability to g_{ij}. To do so we add a probability of 0.01 to each g_{ij} and normalize the modified vector to sum to one, such that $\hat{g}_{ij} = (g_{ij} + 0.01) / \sum_j (g_{ij} + 0.01)$. The practice of assigning some positive measure over the entire range of a random variable is common in studies of combining probability distributions to avoid sensitive behavior in calculations with zero probabilities (Gelfand, Mallick, and Dey).

Expert data are combined using equation (5) where μ^k is set to equal ρ^k. This assumption supposes that ex-ante S expects the experts to supply the same probability vector as he himself does, which is a suitable assumption for if all experts supply $H_i = \rho^k$ then the posterior will equal the prior. We form $\pi(\theta \mid \theta_i^k = j)$ numerically and consistent with the marginals μ^k and ρ^k using a method proposed by Johnson and Tennenbein. In this procedure, two correlated random variates are created by forming a weighted linear combination of two independent normal random variables. These variates can be used to create random variables of any distribution function using the inverse transform method. Johnson and Tennenbein provide the weights that are necessary to reach a given level of

Spearman rank correlation between the variates of any distribution and we draw correlated variates with Spearman rank correlations $SPR = 0.13$ and $SPR = 0.09$.[9] These two values were chosen because the posteriors yield a suitable mix of the collected opinions while illustrating how the correlation structure influences the weighting between S's and the experts' opinion.

Using this method, we draw 10,000 variates to numerically estimate $\hat{\pi}(\theta \mid \theta_i^k = j)$ where this large number of draws is chosen to ensure stable estimates of the tails of the distribution. The posterior is calculated via (5). Since $\hat{\pi}(\theta \mid \theta_i^k = j)$ is an estimate of all the possible $\pi(\theta \mid \theta_i^k = j)$ given the marginals and the correlation structure, it is random and we reiterate the procedure 1000 times and report the mean posterior interval probabilities along with their respective t-values. Standard errors of the estimated posterior distribution suggest a stabilization after 1000 draws.

Using the mean posterior distributions, we draw 1000 realizations of changes in cost, yield, and share allocated to the fresh market in each region for each scenario. For each of these 1000 realizations, we calculate the change in the marginal cost function via (9) and compute the changes in economic surplus accordingly via system (7).[10] The Monte Carlo analysis is repeated for the three different values of τ for the demand shift in the case of banning all OPs.

Results

The mean posterior distributions are shown in tables 16-27 for $SPR = 0.13$ and tables 28-39 for $SPR = 0.09$. As in tables 4-27, the roman numbers I-VII denote as the intervals for the changes in cost, yield, and share of production marketed to the fresh market. To aid the interpretation of the results we repeat the prior and the unweighted arithmetic mean of the expert opinion in the row "expert" and present the mean estimate of the posterior together with the t-value that was calculated from the 1000 estimates of the posterior. For *SPR* = 0.13, tables 16-18 show the posteriors for a ban of APM one year after the ban, tables 19-21 show the same for a ban on all OPs. Tables 22-24 and 25-27 repeat the same for five-year impacts. Tables 28-39 are organized similarly for *SPR* = 0.09.

Two important observations can be made. For smaller *SPR* the correlation is lower, and the expert opinions weigh less in the posterior and S has more influence. This is consistent with the result we derived for linear mixing distribution $\pi(\theta \mid \theta_i^k = j)$ that we derived in Appendix 3A. Results also show that the posterior is not a simple linear combination between the prior and the experts' opinion. In particular, for each interval the experts' opinions over *all* intervals will enter. Therefore the posterior will not necessarily lie between the prior and the mean of the expert estimates. Also as the number of expert opinion that enter the posterior gets larger, the opinion of each individual expert becomes less important.

Table 40 and 41 show some summary statistics of the posterior distributions for the marginal cost changes in all regions for all scenarios. Marginal cost increases are stronger after a ban on all OPs than after a ban of APM. After a ban on APM they grow larger when going from the short run to the long run in the East and in the West, but in the Central they are smaller in the long run than in the short run. For the OPs marginal cost impacts are less severe in the long run.

Weaker or stronger impacts in the long run are both plausible scenarios. Over time, growers might become more flexible to adapt their production system to the loss of the pesticides and learn how to use alternative means. New technologies might become available as well. On the other hand, insect pests have their own complex population dynamics. For instance, a possible alternative for the OPs are pyrethroids, a class of insecticides that is effective against the same pests but that is more toxic to beneficial insects. Switching from OPs to pyrethroids could trigger an increase in mite populations that are otherwise partly controlled by beneficials. These problems with secondary pests might not be significant in the first year after the loss of OPs but could become more severe in later years. Another aspect is that the use of pheromones for mating disruption, a tactic that is used to control the key pest population of codling moths, seems to be relatively effective in the northwestern United States but it does not seem to work as well in some other regions. Furthermore, although many substitute OPs are available to replace APM, losing APM could be disruptive to integrated pest management systems that rely on switching between different insecticides as a resistance management strategy.

Using 1000 realizations of the marginal cost function distributions, we calculate the welfare losses for each realization using system (7). For each posterior calculation with *SPR* = 0.13 and *SPR* = 0.09, we calculate the welfare impacts assuming $\tau = 0$, $\tau = 1.25\%$ and $\tau = 2.5\%$. The resulting distributions of economic surplus changes are summarized in table 42 for *SPR* = 0.13 and in table 43 for *SPR* = 0.09. We can see that banning all OPs would have much stronger welfare impacts than banning APM only if τ=0%. In addition, the variation of the estimate increases when going from short run to long run. As we increase τ, welfare losses after a banning OPs become smaller and expected welfare losses of banning APM exceed those of banning all OPs if τ=2.5%. However, the variance of the estimate for losing all OPs is also much larger and a ranking of the welfare impacts will depend on the decision-maker's utility function.

Our objective is compare the welfare implications of the two policy options of banning APM or all OPs and for a comprehensive comparison of the two distributions in their welfare properties a non-parametric test for stochastic dominance of first- and second-degree as introduced by Anderson is implemented. The H_0 of the test is no dominance of one distribution over the other and it is tested against the H_1 stating that one distribution dominates the other. The test arises as a transformation of a Chi-squared goodness of fit test that uses a transformation of the total deviations between two distributions.[11] In addition to a simple Chi-squared test, the Anderson test allows us to see the location and direction of disagreement in the distributions. We use the test to compare the distributions of welfare impacts of a ban on APM versus the welfare implications of a ban on OPs, both in the short run and in the long run.

We briefly summarize the test procedure. Under the null, both samples are assumed to originate from the same population. We form a joint sample from the OPs and APM sample each for the short run and long run, and divide it into a partition with equal cell probabilities. For our implementation a partition into 10 cells is chosen and the probability of being in the cell equals 0.1 under the null. The cell length *d* is defined by this partitioning, i.e. it is defined such that 0.1 observations of the joint sample are assigned to each cell. The cell frequencies x^A and x^B using this same partition for the separated samples are calculated together with cell probabilities $p^A=x^A/n^A$ and $p^B=x^B/n^B$, n^A and n^B being the respective sample sizes. Superscript A (B) denotes here the sample of welfare distribution after a ban on APM (OPs).

The x^A and x^B follow a multinomial distribution and a normal approximation is appropriate if $n^i p^i > 5$, i = A, B. Then $v = x^A / n^A - x^B / n^B$ is asymptotically distributed as $N(0, m\Omega)$ and $v'\Omega^{-1}v$ is asymptotically distributed as $\chi^2(k-1)$. Here, Ω^{-1} is the general inverse of Ω, $m = n^{-1}(n^A + n^B)/n^A n^B$, and Ω is defined as in Anderson (p. 1185).

FSD is defined by differences in cumulative distributions and these are approximated by forming the cumulative cell probabilities as

$$I_f v = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ 1 & 1 & 0 & \cdots & 0 \\ 1 & 1 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & 1 & \cdots & 1 \end{bmatrix} v.$$

For SSD, the integral of the cumulative distribution is approximated using a trapezoidal rule for approximating integrals as

$$I_F I_f v = 0.5 \begin{bmatrix} d_1 & 0 & 0 & \cdots & 0 \\ d_1 + d_2 & d_2 & 0 & \cdots & 0 \\ d_1 + d_2 & d_2 + d_3 & d_3 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_1 + d_2 & d_2 + d_3 & d_3 + d_4 & \cdots & d_{10} \end{bmatrix} I_f v.$$

Dividing each entry of these vectors by its standard deviation gives the vector of test statistics.

Because the test gives rise to a vector of test statistics, it requires multiple comparisons. We adopt the same convention as Anderson: the hypothesis of dominance of distribution APM over OPs requires that no element is significantly larger than 0 whilst at least one element is significantly less than 0. Given the symmetry of the test, the dominance of OPs over APM is established if no element is significantly smaller than 0 whilst at least one element is significantly larger than 0. Test statistics are compared to the table of the studentized maximum modulus distribution and the 1% critical value for a test with 10 cells is 3.29 (Stoline and Ury).

Results for the test statistics are given in tables 44-46 and tables 47-49 for *SPR* = 0.13 and *SPR* = 0.09, respectively. The left four columns summarize the test for the short-run distributions; the right four columns repeat the same for the long run. For each, the first two columns give the cell probabilities, and the second two columns give the test statistics for FSD and SSD. Starting from the posterior calculation with *SPR* = 0.13, for τ =0, the distributions of economic surplus impacts after a ban on APM are preferable to those after a ban on OPs in the SSD sense in the short run, but the distribution cannot be ordered in the FSD sense. In the long run the policy of banning APM clearly dominates the one of banning all OPs in both the sense of FSD and SSD. Given τ =1.25%, the distributions can only be order in the SSD sense both in the short run and in the long run, while they cannot be ordered in the FSD sense in either case. For τ =2.5%, the ordering is reversed for the long-run distributions, and banning all OPs would now be the preferred option in the FSD and in the SSD sense, while at the same time the short-run distributions cannot be ordered. The results for *SPR* = 0.09 (tables 47-49) are relatively similar, but for the fact that the difference between the two distributions is in general smaller.

Using the vector of test statistics other interesting conclusions can be drawn by noting that for our case the vector of test statistics switches sign at only one point if the test is inconclusive. Looking for instance at the test for FSD in table 45, the welfare distribution after a loss of APM is superior for the first six deciles but inferior for the last four. Therefore a policy-maker who is concerned about the probability of large losses but cares less about the ordering of the policies for smaller impacts might still prefer the option of canceling APM. Hence the test can be informative for preference that do not adhere to the requirements of FSD or SSD, even if the test result itself is inconclusive.

Conclusion

The paper discusses issues of impact uncertainty in welfare analysis and shows how impact distributions can be derived from expert opinion. Resulting distributions of welfare changes can be ordered using a nonparametric test, comparing distributions in the FSD and SSD sense. We demonstrate the methods for the topical example of banning OPs in U.S. apple production.

With regard to organophosphate regulation in U.S. apple production, we have seen that marginal-cost impacts are considerably larger when banning all OPs versus banning APM only. In the case of banning all OPs, short-run impacts are in general more severe than long-run impacts. The order is reversed for banning APM only. When analyzing at the welfare impacts, we must not only consider supply function shifts but also possible changes in the demand function. If the average WTP for apples without OPs increases sufficiently, welfare will increase. In the long run, we found that a 2.5% increase in average WTP is sufficient to offset additional welfare losses resulting from cost increases due to losing all OPs versus APM only.

Estimates of ex-ante welfare impacts of changes in the legal or natural environment are often desired for informed policy decision making. However, in many situations no suitable data are available to predict the distributions of the parameters of change. Such situations arise frequently in the prediction of complex system responses. Woodward and Bishop analyze situations of environmental policy making under pure uncertainty. The here proposed method of combining expert opinion can be useful when trying to move from a state of pure uncertainty over policy outcomes to a state with known probability distributions, so that a welfare analysis under risk becomes feasible.

Experimental data are by their nature created under well-defined conditions that depict a particular situation, but economic studies need information about general behavior. The role of the expert is then to arrive at a prediction of system behavior under general conditions using her expertise to generalize the experimental data. However, the discrepancy between the data needs of natural scientists and economists leads often to tensions in interdisciplinary work (Zilberman and Millok). To give experts the opportunity to express their difficulty in arriving at impact estimates and to ask them for probability distributions rather than for expected values might alleviate the strain on the collaboration.

While the information demand on experts increases, it has been our experience that experts feel more comfortable with their assessment if they can express their uncertainty. Despite the fact that the survey required a considerable time commitment from the experts, a response rate of 58% was achieved for this study. Experts may also be less inclined to factor a risk premium into the reported expected impacts.

The proposed procedure for combining expert opinion is consistent with the laws of probability theory. The correlation structure can be used to give different weights to the Suprabayesian and the experts. The resulting economic surplus distributions can be summarized using different statistical measures depending on the preferences of the policy maker. Given the level of risk aversion or the nature of the project, percentiles of extreme events might for instance be of interest. As shown in this study, outcome distributions can be ordered for any increasing or increasing and concave utility function using a nonparametric test. An interesting extension would be to find a test that would allow ordering welfare measures of higher dimensions for instance the distribution of consumer versus producer surpluses.

Possible other applications that seem immediate are studies of global climate change and the assessment of environmental risks. An interesting agricultural application would be the prediction of resistance development in response to widespread adoption of pesticide resistant plants. In situations where several experimental studies exist, it might be possible to estimate impact distributions from the data directly rather than by using expert opinion. Methods such as empirical Bayes might be a more suitable approach in these situations (Efron).

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Notes

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[3] A sufficient condition for existence of Q^0 is that $Z(Q)$ is continuous, $Z(0) \geq 0$, and $Z(\infty) \leq 0$. For uniqueness we require that $Z(Q)$ is decreasing everywhere.

[4] By using the expected economic surplus criterion we perform a state-dependent welfare comparison. Ready shows that for welfare analysis under uncertainty, state-dependent variables are likely to overestimate the value of a project because affected groups can coinsure each other in states when the project benefits one group and damages another group. In our study however, this coinsurance effect is likely to be small because changes in consumer and producer surplus are strongly correlated through market forces.

[5] The proof of this assertion is a straightforward application of the results by Hadar and Russell.

[6] Roosen et al. found an average WTP of 18% of market value but this value seems rather high and we use the more realistic values of up to 2.5%. The choice of standard deviation was motivated by the relative standard error of WTP found in the same study.

[7] In the survey the regions Northwest and Southwest of the economic model were combined to region West because of fear that not enough experts would participate in our study if the regions were defined to small. The number of experts in the Central is relatively small, because the region is small compared to the two other regions and there are basically only two states, Michigan and Ohio, where apple production is sufficiently important to have extension and industry experts working in apple production.

[8] Looking at equation (5), it is immediately clear that the posterior $p^*(\theta \mid H_1, H_2, ..., H_N) = 0$ if the prior $\rho_j = 0$ no matter how likely all other experts consider the outcome θ^j.

[9] Johnson and Tennenbein propose a method of creating correlated random variates using a weighted linear combination method by forming a weighted sum of independent random variates. They give values for the weights *c* that result in a given level Spearman rank correlation. Because of the discreteness of our distributions, we implement a Monte Carlo study of 1000 iteration to estimate the value of Spearman rank correlation for the two different values of *c* that we use in our study, i.e., $c = 0.0952$ and $c = 0.05$. For these two values of *c*, we estimate a correlation of 0.1308 (0.0160) and 0.0871 (0.0177), respectively, where the numbers in parentheses report standard errors.

[10] The same distribution for marginal cost changes is used for the Northwest and Southwest as growing and pest conditions are very similar in both regions.

[11] Tolley and Pope introduced a similar test of stochastic dominance that was formed as an exact test, i.e. the critical values of the test statistic were derived from the sample. Anderson derives a test statistic that follows a known and tabulated distribution.

Table 1. U.S. Apple Production across Regions

	U.S.	East	Central	Northwest	Southwest
Production (mill. lb.)	10,583.2	2,580.6	1,342.9	5,632.4	1,027.3
Yield (lb.)	23,537.1	17,488.0	14,819.0	33,814.0	22,887.0
Fresh Share (%)	58.3	40.6	44.0	72.0	36.2
Fresh Price (¢/lb.)	21.1	19.2	20.7	21.0	30.1
Proc. Price (¢/lb.)	7.9	8.1	8.9	7.7	7.6

Table 2. Percentage of Acreage Treated with APM and OP

	APM	OP
East	79.3	99.0
Central	91.5	99.5
Northwest	88.1	99.4
Southwest	48.0	88.7

Table 3. Definition of Interval Ranges for Expert Opinion Collection[a]

	I	II	III	IV	V	VI	VII
Cost	dC<-0.5%	-0.5%<dC <0.5%	0.5%<dC <1%	1%<dC <2%	2%<dC <5%	5%<dC <10%	10%<dC <15%
Yield	dY<-10%	-10%<dY <-5%	-5%<dY <-2%	-2%<dY <-1%	-1%<dY <-0.5%	-0.5%<dY <0.5%	0.5%<dY
Fresh Share	$d\alpha < -10\%$	$-10\% < d\alpha$ $< -5\%$	$-5\% < d\alpha$ $< -2\%$	$-2\% < d\alpha$ $< -1\%$	$-1\% < d\alpha$ $< -0.5\%$	$-0.5\% < d\alpha$ $< 0.5\%$	$0.5\% < d\alpha$

[a] dC denotes the change in cost per acre, dY the change in yield per acre and $d\alpha$ denotes the change in share of production allocated to the fresh market.

Table 4. Loss of APM, Year 1, Expert Assessment for Change in Cost[a]

Expert	I	II	III	IV	V	VI	VII
Prior	8.8	11.8	35.3	17.6	11.8	8.8	5.9
E1	0	100	0	0	0	0	0
E2	1	98	1	0	0	0	0
E3	0	0	10	60	20	10	0
E4	0	75	20	5	0	0	0
E5	0	0	10	10	50	25	5
E6	0	30	60	10	0	0	0
E7	0	0	0	0	10	80	10
E8	5	10	20	20	40	5	0
E9	0	10	10	10	30	30	10
E10	0	20	20	40	20	0	0
E11							
E12							
Prior	0.0	5.0	10.0	20.0	50.0	10.0	5.0
C1	0	0	5	40	50	5	0
C2	0	0	0	0	25	25	50
C3	0	0	20	40	40	0	0
C4	0	0	5	5	20	30	40
Prior	5.9	11.8	11.8	17.6	29.4	14.7	8.8
W1	0	0	10	50	30	10	0
W2	0	5	5	5	10	35	40
W3	0	0	0	0	40	60	0
W4	0	0	20	60	20	0	0
W5	0	5	20	60	15	0	0
W6	0	0	0	0	0	0	100
W7	0	20	30	40	10	0	0
W8	0	5	10	10	10	15	50
W9	0	0	10	70	20	0	0
W10	0	0	0	0	10	20	70
W11	5	10	10	10	10	25	30
W12	0	0	0	5	10	20	65
W13	0	100	0	0	0	0	0
W14	10	25	25	25	10	5	0

[a] Rows list the expert estimates for probabilities over intervals I-VII as defined in table 3. E1 identifies first expert for region East, C1 identifies first expert for region Central, and W1 identifies first expert for region West. The row **Prior** at the top of each category list the prior formed by the Suprabayesian.

Table 5. Loss of APM, Year 1, Expert Assessment for Change in Yield

Expert	I	II	III	IV	V	VI	VII
Prior	0.0	0.0	6.1	6.1	13.1	61.6	13.1
E1	0	0	0	0	0	100	0
E2	0	0	0	0	1	98	1
E3	0	0	0	10	20	70	0
E4	0	0	0	0	20	80	0
E5	0	0	0	25	50	25	0
E6	0	0	0	0	25	75	0
E7	0	0	0	5	5	90	0
E8	0	0	10	35	30	20	5
E9							
E10	0	0	0	0	10	80	10
E11	0	0	0	10	80	10	0
E12							
Prior	5.8	6.4	7.0	7.6	8.3	64.9	0.0
C1	0	0	0	0	0	100	0
C2	30	25	25	20	0	0	0
C3	0	0	10	40	40	10	0
C4	0	0	10	60	20	10	0
Prior	5.9	5.9	5.9	5.9	5.9	64.7	5.9
W1	0	0	0	10	10	70	10
W2	40	30	10	10	5	5	0
W3	0	0	0	0	5	95	0
W4	0	0	0	0	0	100	0
W5	0	0	5	5	5	80	5
W6							
W7	0	0	0	0	0	100	0
W8	5	5	10	10	20	50	0
W9	0	0	0	0	10	80	10
W10	0	0	0	0	2.5	95	2.5
W11	35	30	10	10	10	5	0
W12	0	0	0	0	0	100	0
W13	0	0	0	0	0	100	0
W14	0	0	0	0	20	60	20

Table 6. Loss of APM, Year 1, Expert Assessment for Change in Allocation to Fresh

Expert	I	II	III	IV	V	VI	VII
Prior	0.0	5.0	15.0	30.0	30.0	15.0	5.0
E1	0	0	0	0	0	0	100
E2	0	0	0	0	1	98	1
E3	0	0	0	0	20	80	0
E4	0	0	0	10	10	70	10
E5	0	0	20	50	30	0	0
E6	0	0	0	0	10	90	0
E7	0	0	5	90	5	0	0
E8	0	0	5	30	30	30	5
E9	0	10	10	10	20	50	0
E10	0	0	0	10	60	20	10
E11	0	0	0	10	80	10	0
E12							
Prior	0.0	6.1	11.7	14.4	47.8	20.0	0.0
C1	0	0	5	40	40	5	0
C2	0	25	50	25	0	0	0
C3	0	0	40	40	20	0	0
C4	0	0	10	60	20	10	0
Prior	5.9	5.9	5.9	17.6	41.2	17.6	5.9
W1	5	10	50	20	15	0	0
W2	5	5	20	20	15	20	15
W3	0	0	0	0	0	100	0
W4	0	0	0	0	10	80	10
W5	0	0	0	5	10	85	0
W6	0	5	10	15	30	40	0
W7	0	0	0	0	0	100	0
W8	0	0	0	0	75	25	0
W9	0	0	0	0	30	60	10
W10	0	0	0	0	0	100	0
W11	30	25	10	10	10	10	5
W12	0	0	0	0	0	100	0
W13	0	0	0	0	0	100	0
W14	5	5	10	10	10	60	0

Table 7. Loss of OP, Year 1, Expert Assessment Change in Cost

Expert	I	II	III	IV	V	VI	VII
Prior	5.9	5.9	11.8	11.8	29.4	23.5	11.8
E1	0	100	0	0	0	0	0
E2	90	10	0	0	0	0	0
E3	0	0	0	0	20	60	20
E4	10	70	5	5	5	5	0
E5	0	0	0	0	0	20	80
E6	0	0	0	40	60	0	0
E7	0	0	0	0	10	40	50
E8	1	1	1	1	1	5	90
E9	0	0	10	10	10	20	50
E10	0	0	0	20	20	50	10
E11	0	0	0	0	0	0	100
E12	0	0	0	0	10	80	10
Prior	0.0	5.0	5.0	10.0	20.0	50.0	10.0
C1	0	0	5	40	40	10	5
C2	0	0	0	0	0	0	100
C3	0	0	10	40	40	10	0
C4	0	0	0	0	0	30	70
Prior	11.8	23.5	35.3	11.8	5.9	5.9	5.9
W1	0	0	30	50	20	0	0
W2	0	0	10	30	30	20	10
W3	0	0	0	0	20	50	30
W4	0	0	10	40	40	10	0
W5	0	0	10	20	50	15	5
W6	0	5	10	15	30	30	10
W7	0	10	10	20	20	20	20
W8	0	0	0	0	20	30	50
W9	0	0	0	0	0	10	90
W10	0	0	0	0	0	5	95
W11	0	10	10	15	15	25	25
W12	0	0	0	10	25	50	15
W13	0	0	0	20	40	40	0
W14	20	50	10	10	10	0	0

Table 8. Loss of OP, Year 1, Expert Assessment for Change in Yield

Expert	I	II	III	IV	V	VI	VII
Prior	8.8	11.8	17.6	29.4	14.7	11.8	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	0	20	80
E3	0	0	10	50	30	10	0
E4	0	0	0	0	10	80	10
E5	70	20	10	0	0	0	0
E6	0	0	0	20	50	30	0
E7	0	25	50	25	0	0	0
E8	10	20	25	20	15	5	5
E9							
E10	0	10	30	30	20	10	0
E11	0	0	50	50	0	0	0
E12	10	70	10	10	0	0	0
Prior	5.9	5.9	5.9	5.9	11.8	52.9	11.8
C1	0	0	5	20	50	25	0
C2	100	0	0	0	0	0	0
C3	0	40	40	20	0	0	0
C4	0	30	60	10	0	0	0
Prior	2.9	5.9	8.8	11.8	11.8	41.2	17.6
W1	0	0	20	50	30	0	0
W2	30	30	20	10	5	5	0
W3	30	40	30	0	0	0	0
W4	0	0	20	60	20	0	0
W5	0	0	0	15	60	25	0
W6	10	20	10	20	20	20	0
W7	5	15	20	30	20	10	0
W8	0	5	10	50	20	15	0
W9	0	5	15	30	30	20	0
W10	0	5	5	5	5	80	0
W11	30	30	15	10	10	5	0
W12	0	0	0	0	0	100	0
W13	0	0	0	0	0	100	0
W14	20	20	20	40	0	0	0

Table 9. Loss of OP, Year 1, Expert Assessment for Change in Allocation to Fresh

Expert	I	II	III	IV	V	VI	VII
Prior	11.8	23.5	29.4	11.8	8.8	8.8	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	1	98	1
E3	0	10	50	30	10	0	0
E4	0	0	0	5	10	80	5
E5	80	20	0	0	0	0	0
E6	0	0	0	5	25	70	0
E7	80	15	5	0	0	0	0
E8	0	5	30	30	20	10	5
E9	100	0	0	0	0	0	0
E10	0	0	20	60	20	0	0
E11	0	50	50	0	0	0	0
E12	20	20	30	20	10	0	0
Prior	10.0	30.0	30.0	15.0	10.0	5.0	0.0
C1	5	20	50	20	5	0	0
C2	100	0	0	0	0	0	0
C3	0	60	40	0	0	0	0
C4	60	30	10	0	0	0	0
Prior	2.9	8.8	11.8	17.6	29.4	17.6	11.8
W1	45	35	10	10	0	0	0
W2	10	25	30	20	10	5	0
W3	0	0	20	20	20	40	0
W4	0	0	0	0	20	20	60
W5	0	5	20	40	25	10	0
W6	50	30	10	5	5	0	0
W7	10	20	30	20	10	10	0
W8	0	0	10	20	50	10	10
W9	0	10	30	30	20	10	0
W10	0	0	0	0	0	100	0
W11	25	25	20	10	10	5	5
W12	10	60	20	5	5	0	0
W13	0	0	0	0	0	100	0
W14	0	5	25	40	25	5	0

Table 10. Loss of APM, Year 5, Expert Assessment for Change in Cost

Expert	I	II	III	IV	V	VI	VII
Prior	5.9	8.8	11.8	29.4	23.5	11.8	8.8
E1	0	100	0	0	0	0	0
E2	1	98	1	0	0	0	0
E3	0	0	0	10	40	40	10
E4	5	70	10	10	5	0	0
E5	0	80	10	10	0	0	0
E6	0	25	60	15	0	0	0
E7	0	0	0	0	0	0	100
E8	10	30	30	20	10	0	0
E9	0	0	0	10	20	20	50
E10	0	10	20	50	20	0	0
E11	0	0	30	40	30	0	0
E12	0	100	0	0	0	0	0
Prior	10.0	50.0	20.0	10.0	5.0	5.0	0.0
C1	0	5	40	30	20	5	0
C2	50	25	25	0	0	0	0
C3	0	0	0	20	40	40	0
C4	10	70	10	10	0	0	0
Prior	10.0	10.0	10.0	30.0	20.0	15.0	5.0
W1	40	50	10	0	0	0	0
W2	10	15	20	20	20	10	5
W3	10	80	10	0	0	0	0
W4	0	10	50	30	10	0	0
W5	0	10	10	60	10	10	0
W6	50	10	10	10	10	10	0
W7	0	5	30	20	20	20	5
W8	40	20	10	10	10	5	5
W9	0	2	40	30	28	0	0
W10	40	40	10	5	5	0	0
W11	20	50	10	10	5	5	0
W12	5	40	40	15	0	0	0
W13	100	0	0	0	0	0	0
W14	50	20	15	15	0	0	0

Table 11. Loss of APM, Year 5, Expert Assessment for Change in Yield

Expert	I	II	III	IV	V	VI	VII
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	1	98	1
E3	0	0	10	50	30	10	0
E4	0	0	0	0	20	80	0
E5	0	0	0	10	10	80	0
E6	0	0	0	0	30	70	0
E7	0	5	15	80	0	0	0
E8	0	0	5	5	20	60	10
E9	50	20	20	10	0	0	0
E10	0	10	60	20	10	0	0
E11	0	0	0	10	80	10	0
E12	0	0	0	0	0	100	0
Prior	5.7	6.3	6.8	7.4	11.4	51.1	11.4
C1	0	0	0	0	0	100	0
C2	10	10	20	50	10	0	0
C3	0	0	0	0	20	40	40
C4	0	0	10	60	20	10	0
Prior	5.0	6.0	9.0	10.0	20.0	30.0	20.0
W1	0	10	50	40	0	0	0
W2	15	30	20	15	10	5	5
W3	0	0	0	0	0	100	0
W4	0	0	0	10	80	10	0
W5	0	0	5	10	20	60	5
W6	0	5	10	15	40	30	0
W7	0	0	0	10	10	80	0
W8	5	5	5	15	15	40	15
W9	0	0	0	0	10	80	10
W10	0	0	0	0	0	100	0
W11	20	40	10	10	10	5	5
W12	0	0	0	0	0	100	0
W13							
W14	50	20	10	10	10	0	0

Table 12. Loss of APM, Year 5, Expert Assessment for Change in Allocation to Fresh

Expert	I	II	III	IV	V	VI	VII
Prior	8.8	17.6	29.4	17.6	11.8	8.8	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	1	98	1
E3	0	10	50	30	10	0	0
E4	0	0	0	0	5	90	5
E5	0	0	0	10	10	80	0
E6	0	0	0	5	10	85	0
E7	85	10	5	0	0	0	0
E8	0	0	0	10	15	60	15
E9	100	0	0	0	0	0	0
E10	0	0	0	10	40	40	10
E11	0	0	0	10	80	10	0
E12	0	0	0	0	0	100	0
Prior	5.9	11.8	35.3	17.6	11.8	8.8	8.8
C1	5	40	40	10	5	0	0
C2	0	5	10	20	60	5	0
C3	0	0	0	0	20	40	40
C4	5	10	50	30	5	0	0
Prior	5.9	5.9	5.9	5.9	17.6	47.1	11.8
W1	40	25	25	10	0	0	0
W2	5	5	10	30	20	20	10
W3	0	0	0	0	10	90	0
W4	0	0	0	0	0	20	80
W5	0	0	10	10	20	50	10
W6	0	5	5	5	15	70	0
W7	0	0	0	10	20	40	30
W8	0	0	0	10	20	70	0
W9	0	0	0	0	10	80	10
W10	0	0	0	0	0	100	0
W11	5	5	15	15	25	25	10
W12	0	0	0	0	0	100	0
W13	0	0	0	0	0	100	0
W14	20	40	20	20	0	0	0

Table 13. Loss of OP, Year 5, Expert Assessment Change in Cost

Expert	I	II	III	IV	V	VI	VII
Prior	5.9	8.8	8.8	11.8	11.8	35.3	17.6
E1	0	20	50	30	0	0	0
E2	20	60	20	0	0	0	0
E3	0	0	0	0	0	0	100
E4	0	60	10	10	10	10	0
E5	0	0	0	0	10	20	70
E6	0	0	0	70	30	0	0
E7	0	0	0	0	10	30	60
E8	0	5	5	5	5	5	75
E9	0	0	0	10	10	10	70
E10	0	0	0	30	60	10	0
E11	0	0	0	0	0	0	100
E12	0	0	0	10	10	10	70
Prior	5.9	8.8	8.8	11.8	17.6	29.4	17.6
C1	0	0	0	0	10	30	60
C2	0	0	0	0	0	0	100
C3	20	60	20	0	0	0	0
C4	0	0	0	0	10	20	70
Prior	11.8	11.8	17.6	29.4	11.8	11.8	5.9
W1	0	0	0	0	10	40	50
W2	5	10	20	20	20	15	10
W3	0	0	0	0	0	90	10
W4	0	0	0	20	60	20	0
W5	0	5	10	20	50	15	0
W6	0	0	0	0	10	10	80
W7	0	5	10	20	20	20	25
W8	0	0	0	0	0	40	60
W9	0	0	0	0	0	5	95
W10	0	0	0	0	0	0	100
W11	5	10	10	10	15	20	30
W12	0	0	0	10	20	50	20
W13	0	0	0	0	0	0	100
W14	0	0	0	20	20	20	40

Table 14. Loss of OP, Year 5, Expert Assessment for Change in Yield

Expert	I	II	III	IV	V	VI	VII
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	20	60	20
E3	20	60	20	0	0	0	0
E4	0	0	0	10	10	80	0
E5	0	20	50	30	0	0	0
E6	0	0	0	40	50	10	0
E7	50	40	10	0	0	0	0
E8	0	0	0	0	15	70	15
E9							
E10	0	0	20	60	10	10	0
E11	0	0	20	70	10	0	0
E12	50	30	10	10	0	0	0
Prior	5.0	10.0	15.0	40.0	15.0	10.0	5.0
C1	0	5	40	40	15	0	0
C2	50	50	0	0	0	0	0
C3							
C4	0	40	60	0	0	0	0
Prior	5.0	10.0	15.0	40.0	15.0	10.0	5.0
W1	10	50	20	10	10	0	0
W2	30	30	20	10	5	5	0
W3	80	20	0	0	0	0	0
W4	0	0	0	20	60	20	0
W5	0	0	0	10	55	35	0
W6	0	0	0	50	30	20	0
W7	5	20	30	20	15	10	0
W8	0	0	10	30	30	30	0
W9	10	25	20	20	20	5	0
W10	0	0	0	0	0	100	0
W11	10	35	20	10	10	10	5
W12	0	0	0	0	0	100	0
W13							
W14	10	40	20	20	10	0	0

Table 15. Loss of OP, Year 5, Expert Assessment for Change in Allocation to Fresh

Expert	I	II	III	IV	V	VI	VII
Prior	17.6	35.3	14.7	11.8	8.8	5.9	5.9
E1	0	0	0	0	0	100	0
E2	0	0	0	0	20	60	20
E3	0	50	30	20	0	0	0
E4	0	0	5	5	5	80	5
E5	50	30	20	0	0	0	0
E6	0	0	0	30	50	20	0
E7	60	40	0	0	0	0	0
E8	0	0	0	10	40	40	10
E9							
E10	0	20	40	20	20	0	0
E11	0	30	60	10	0	0	0
E12	30	30	30	10	0	0	0
Prior	17.6	35.3	11.8	11.8	8.8	8.8	5.9
C1	70	20	10	0	0	0	0
C2	30	40	20	10	0	0	0
C3	0	0	0	0	0	40	60
C4	80	20	0	0	0	0	0
Prior	8.8	8.8	17.6	29.4	17.6	11.8	5.9
W1	30	30	20	10	10	0	0
W2	5	5	15	30	20	15	10
W3	0	0	40	20	20	20	0
W4	0	0	0	0	0	20	80
W5	0	10	20	40	20	10	0
W6	0	0	50	30	20	0	0
W7	10	20	20	20	20	10	0
W8	0	15	30	20	20	10	5
W9	0	10	30	25	25	10	0
W10	0	0	0	0	0	100	0
W11	10	25	25	15	10	10	5
W12	0	0	0	0	0	100	0
W13	20	40	40	0	0	0	0
W14	40	20	20	20	0	0	0

Table 16. Loss of APM, Year 1, Change in Cost, *SPR* = 0.13[a]

	I	II	III	IV	V	VI	VII
East							
Prior	8.8	11.8	35.3	17.6	11.8	8.8	5.9
Expert	1.5	33.0	15.0	15.4	16.8	15.0	3.3
Posterior	7.8	11.4	35.6	18.1	12.1	9.1	5.8
t-value	3.8	4.7	9.2	5.8	4.5	3.7	3.0
Central							
Prior	0.0	5.0	10.0	20.0	50.0	10.0	5.0
Expert	0.0	0.9	8.0	21.0	32.8	15.1	22.2
Posterior	0.0	3.2	7.6	17.2	52.0	12.7	7.3
t-value	0.0	6.1	8.9	13.9	31.2	10.9	8.1
West							
Prior	5.9	11.8	11.8	17.6	29.4	14.7	8.8
Expert	1.9	12.3	10.3	23.3	14.0	13.6	24.6
Posterior	2.2	6.5	8.1	14.6	31.5	20.7	16.4
t-value	2.4	3.5	3.6	5.0	7.5	5.4	4.3

[a] Rows show the probability estimates over the intervals I-VII. For convenience, we repeat the prior from table 4 and list a summary statistic of the expert opinion using the arithmetic mean of all probabilities supplied by experts in the respective regions. The row "posterior" gives the mean estimate of the posterior obtained in a Monte Carlo of 1000 iterations and the row "t-value" reports the corresponding t-value.

Table 17. Loss of APM, Year 1, Change in Yield, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	0.0	0.0	6.1	6.1	13.1	61.6	13.1
Expert	0.0	0.0	1.9	9.0	23.9	62.7	2.5
Posterior	0.0	0.0	8.7	8.0	15.8	59.1	8.4
t-value	0.0	0.0	6.2	6.0	8.9	26.6	7.0
Central							
Prior	5.8	6.4	7.0	7.6	8.3	64.9	0.0
Expert	8.0	6.8	11.6	29.2	15.1	29.2	0.0
Posterior	8.3	8.3	8.5	8.8	9.1	57.1	0.0
t-value	7.4	7.6	7.9	7.8	8.5	29.2	0.0
West							
Prior	5.9	5.9	5.9	5.9	5.9	64.7	5.9
Expert	6.7	5.6	3.5	4.2	7.2	68.5	4.3
Posterior	5.3	5.7	5.8	5.9	5.9	66.0	5.4
t-value	9.1	10.5	11.0	11.2	11.1	62.8	11.7

Table 18. Loss of APM, Year 1, Change in Allocation to Fresh, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	0.0	5.0	15.0	30.0	30.0	15.0	5.0
Expert	0.0	1.8	4.4	19.0	23.8	39.4	11.7
Posterior	0.0	0.8	4.8	17.9	32.2	27.7	16.5
t-value	0.0	2.1	3.9	6.3	7.4	6.0	3.6
Central							
Prior	0.0	6.1	11.7	14.4	47.8	20.0	0.0
Expert	0.0	6.9	26.1	41.3	21.0	4.7	0.0
Posterior	0.0	9.7	15.3	16.9	44.8	13.3	0.0
t-value	0.0	7.3	10.5	11.5	23.3	11.4	0.0
West							
Prior	5.9	5.9	5.9	17.6	41.2	17.6	5.9
Expert	3.9	4.3	7.6	6.3	14.6	59.7	3.6
Posterior	1.2	2.0	2.6	9.3	36.2	29.9	18.8
t-value	1.3	1.4	1.3	2.5	4.4	3.6	2.0

Table 19. Loss of OP, Year 1, Change in Cost, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	5.9	5.9	11.8	11.8	29.4	23.5	11.8
Expert	8.8	15.0	2.2	6.9	11.5	22.7	32.9
Posterior	2.6	3.5	8.3	9.5	28.3	28.7	19.0
t-value	2.1	2.2	3.3	3.4	6.0	5.9	4.0
Central							
Prior	0.0	5.0	5.0	10.0	20.0	50.0	10.0
Expert	0.0	0.9	4.5	19.8	19.8	12.7	42.2
Posterior	0.0	3.4	3.8	8.3	18.3	53.3	12.9
t-value	0.0	4.3	4.3	6.5	10.0	23.4	8.0
West							
Prior	11.8	23.5	35.3	11.8	5.9	5.9	5.9
Expert	2.3	5.9	7.6	16.3	22.3	21.3	24.3
Posterior	0.3	2.7	14.4	13.5	12.0	17.2	39.9
t-value	1.2	1.9	2.4	1.8	1.4	1.6	2.6

Table 20. Loss of OP, Year 1, Change in Yield, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	8.8	11.8	17.6	29.4	14.7	11.8	5.9
Expert	8.6	13.3	16.7	18.4	11.6	22.6	9.0
Posterior	5.7	9.5	16.0	30.4	16.7	14.2	7.4
t-value	5.4	7.2	9.4	15.2	9.9	9.4	6.4
Central							
Prior	5.9	5.9	5.9	5.9	11.8	52.9	11.8
Expert	24.3	17.3	25.5	12.6	12.6	6.8	0.9
Posterior	13.0	10.1	8.8	7.9	13.9	41.6	4.7
t-value	5.6	5.2	5.0	4.7	6.8	15.2	5.1
West							
Prior	2.9	5.9	8.8	11.8	11.8	41.2	17.6
Expert	9.3	12.3	13.3	22.3	15.6	26.3	0.9
Posterior	15.6	16.9	17.5	15.9	11.6	20.0	2.5
t-value	2.5	3.2	3.5	3.8	3.6	5.5	3.2

Table 21. Loss of OP, Year 1, Change in Allocation to Fresh, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	11.8	23.5	29.4	11.8	8.8	8.8	5.9
Expert	22.7	10.3	15.3	12.6	8.4	28.8	1.8
Posterior	9.0	21.8	30.1	12.8	9.7	9.9	6.7
t-value	3.1	5.1	6.8	3.7	3.2	3.3	2.6
Central							
Prior	10.0	30.0	30.0	15.0	10.0	5.0	0.0
Expert	39.9	26.9	24.5	5.7	2.1	0.9	0.0
Posterior	16.4	36.0	27.7	11.2	6.2	2.4	0.0
t-value	10.2	18.3	16.2	9.3	6.9	4.5	0.0
West							
Prior	2.9	8.8	11.8	17.6	29.4	17.6	11.8
Expert	10.9	15.3	16.0	15.6	14.3	22.0	5.9
Posterior	8.5	17.0	17.3	20.2	23.9	9.3	3.7
t-value	2.3	4.4	4.7	5.7	6.9	4.4	3.3

Table 22. Loss of APM, Year 5, Change in Cost, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	11.8	29.4	23.5	11.8	8.8
Expert	2.2	40.9	13.5	13.8	10.7	5.6	13.4
Posterior	11.9	14.3	15.9	30.1	17.7	6.7	3.5
t-value	2.1	2.4	2.8	4.6	3.5	2.3	1.8
Central							
Prior	10.0	50.0	20.0	10.0	5.0	5.0	0.0
Expert	15.1	24.5	18.6	15.1	15.1	11.6	0.0
Posterior	7.6	46.9	21.5	11.5	6.0	6.5	0.0
t-value	10.4	33.6	18.3	13.3	9.9	10.4	0.0
West							
Prior	10.0	10.0	10.0	30.0	20.0	15.0	5.0
Expert	2.0	5.2	9.4	17.1	20.0	26.2	20.0
Posterior	1.5	2.8	4.0	18.6	22.6	29.3	21.3
t-value	2.5	2.7	2.9	4.9	4.6	4.8	3.0

Table 23. Loss of APM, Year 5, Change in Yield, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
Expert	4.8	3.7	9.5	15.3	16.6	48.3	1.8
Posterior	1.2	3.1	8.6	28.4	23.6	17.7	17.3
t-value	1.1	1.5	2.4	3.8	3.0	2.2	2.0
Central							
Prior	5.7	6.3	6.8	7.4	11.4	51.1	11.4
Expert	3.3	3.3	7.9	26.6	12.6	36.0	10.3
Posterior	6.2	6.7	7.2	7.8	11.7	50.4	10.0
t-value	8.8	9.2	9.6	9.8	12.0	32.5	10.5
West							
Prior	5.0	6.0	9.0	10.0	20.0	30.0	20.0
Expert	7.4	8.8	8.8	10.6	15.7	44.8	3.8
Posterior	8.5	8.9	12.2	12.2	21.5	25.6	11.2
t-value	4.0	4.4	5.4	5.7	8.1	9.8	6.7

Table 24. Loss of APM, Year 5, Change in Allocation to Fresh, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	8.8	17.6	29.4	17.6	11.8	8.8	5.9
Expert	15.3	2.5	5.2	6.8	14.3	52.6	3.3
Posterior	2.0	7.2	20.1	18.9	17.4	16.9	17.6
t-value	1.2	1.9	2.7	2.3	2.1	2.0	1.7
Central							
Prior	5.9	11.8	35.3	17.6	11.8	8.8	8.8
Expert	3.3	13.8	24.3	15.0	22.0	11.4	10.3
Posterior	4.8	10.6	34.4	18.2	12.5	9.6	9.9
t-value	12.7	20.0	43.9	30.5	25.2	22.5	24.1
West							
Prior	5.9	5.9	5.9	5.9	17.6	47.1	11.8
Expert	5.6	6.3	6.6	8.3	10.3	52.0	10.9
Posterior	5.1	5.5	5.7	5.8	17.9	48.7	11.3
t-value	7.4	7.5	8.2	8.1	14.9	30.4	11.0

Table 25. Loss of OP, Year 5, Change in Cost, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	8.8	11.8	11.8	35.3	17.6
Expert	2.5	12.2	7.6	13.8	12.2	8.3	43.4
Posterior	2.6	5.1	6.1	9.4	10.4	39.0	27.4
t-value	2.1	2.9	3.0	3.6	3.8	8.3	5.9
Central							
Prior	5.9	8.8	8.8	11.8	17.6	29.4	17.6
Expert	5.6	15.0	5.6	0.9	5.6	12.6	54.7
Posterior	3.7	6.6	7.2	10.4	16.8	32.0	23.2
t-value	5.1	6.7	7.0	8.3	10.7	15.6	12.5
West							
Prior	11.8	11.8	17.6	29.4	11.8	11.8	5.9
Expert	1.6	2.9	4.3	8.9	16.0	24.0	42.3
Posterior	0.2	0.7	2.4	11.3	12.6	26.8	45.9
t-value	1.0	1.1	1.3	1.8	1.5	1.9	2.4

Table 26. Loss of OP, Year 5, Change in Yield, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
Expert	11.1	13.7	12.0	19.6	10.7	29.0	3.9
Posterior	4.9	8.3	17.3	36.0	18.3	9.3	5.9
t-value	2.5	3.2	5.1	8.2	5.3	3.6	2.9
Central							
Prior	5.0	10.0	15.0	40.0	15.0	10.0	5.0
Expert	16.5	30.5	32.1	13.4	5.6	0.9	0.9
Posterior	8.4	13.8	18.0	38.9	11.6	6.6	2.6
t-value	8.5	12.0	13.4	24.4	11.1	8.6	5.7
West							
Prior	5.0	10.0	15.0	40.0	15.0	10.0	5.0
Expert	16.5	30.5	32.1	13.4	5.6	0.9	0.9
Posterior	8.4	13.8	18.0	38.9	11.6	6.6	2.6
t-value	8.5	12.0	13.4	24.4	11.1	8.6	5.7

Table 27. Loss of OP, Year 5, Change in Allocation to Fresh, *SPR* = 0.13

Expert	I	II	III	IV	V	VI	VII
East							
Prior	17.6	35.3	14.7	11.8	8.8	5.9	5.9
Expert	12.8	17.9	16.7	9.9	12.4	26.4	3.9
Posterior	7.8	27.0	15.6	14.6	12.8	9.8	12.4
t-value	3.6	6.1	4.3	3.9	3.4	2.9	3.1
Central							
Prior	17.6	35.3	11.8	11.8	8.8	8.8	5.9
Expert	43.0	19.6	7.9	3.3	0.9	10.3	15.0
Posterior	20.2	36.7	11.5	11.1	8.1	7.7	4.7
t-value	13.8	21.4	10.7	10.5	8.9	9.0	7.3
West							
Prior	8.8	8.8	17.6	29.4	17.6	11.8	5.9
Expert	8.6	12.6	21.6	16.3	11.9	21.3	7.6
Posterior	7.3	8.0	17.1	30.1	18.7	12.6	6.3
t-value	4.3	4.9	7.4	10.9	8.3	6.4	4.5

Table 28. Loss of APM, Year 1, Change in Cost, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	8.8	11.8	35.3	17.6	11.8	8.8	5.9
Experts	1.5	33.0	15.0	15.4	16.8	15.0	3.3
Posterior	8.5	11.6	35.1	17.8	12.0	9.0	6.1
t-value	3.9	4.4	9.5	5.9	4.7	3.9	2.9
Central							
Prior	0.0	5.0	10.0	20.0	50.0	10.0	5.0
Experts	0.0	0.9	8.0	21.0	32.8	15.1	22.2
Posterior	0.0	4.0	8.7	18.6	51.3	11.3	6.1
t-value	0.0	6.8	9.4	14.2	30.7	10.5	7.4
West							
Prior	5.9	11.8	11.8	17.6	29.4	14.7	8.8
Experts	1.9	12.3	10.3	23.3	14.0	13.6	24.6
Posterior	3.8	8.8	9.8	16.1	31.0	18.0	12.6
t-value	2.6	3.8	4.1	5.1	7.4	4.9	3.8

Table 29. Loss of APM, Year 1, Change in Yield, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	0.0	0.0	6.1	6.1	13.1	61.6	13.1
Experts	0.0	0.0	1.9	9.0	23.9	62.7	2.5
Posterior	0.0	0.0	7.6	7.1	14.4	60.3	10.6
t-value	0.0	0.0	5.7	5.7	8.7	26.5	8.0
Central							
Prior	5.8	6.4	7.0	7.6	8.3	64.9	0.0
Experts	8.0	6.8	11.6	29.2	15.1	29.2	0.0
Posterior	7.0	7.4	7.8	8.2	8.7	60.9	0.0
t-value	7.0	7.4	7.6	7.6	8.0	34.2	0.0
West							
Prior	5.9	5.9	5.9	5.9	5.9	64.7	5.9
Experts	6.7	5.6	3.5	4.2	7.2	68.5	4.3
Posterior	5.7	5.8	5.9	5.9	5.9	65.1	5.8
t-value	11.0	11.5	11.1	11.3	12.0	64.1	12.1

Table 30. Loss of APM, Year 1, Change in Allocation to Fresh, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	0.0	5.0	15.0	30.0	30.0	15.0	5.0
Experts	0.0	1.8	4.4	19.0	23.8	39.4	11.7
Posterior	0.0	2.3	9.2	24.2	32.6	21.8	9.9
t-value	0.0	2.3	4.2	7.4	7.7	5.4	3.0
Central							
Prior	0.0	6.1	11.7	14.4	47.8	20.0	0.0
Experts	0.0	6.9	26.1	41.3	21.0	4.7	0.0
Posterior	0.0	7.9	13.6	15.7	46.4	16.4	0.0
t-value	0.0	6.8	10.0	11.0	24.2	12.0	0.0
West							
Prior	5.9	5.9	5.9	17.6	41.2	17.6	5.9
Experts	3.9	4.3	7.6	6.3	14.6	59.7	3.6
Posterior	3.0	3.8	4.2	13.6	39.6	23.9	11.9
t-value	1.4	1.5	1.6	2.7	5.0	3.3	1.8

Table 31. Loss of OP, Year 1, Change in Cost, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	5.9	5.9	11.8	11.8	29.4	23.5	11.8
Experts	8.8	15.0	2.2	6.9	11.5	22.7	32.9
Posterior	4.2	4.6	9.8	10.8	29.1	26.3	15.3
t-value	2.3	2.4	3.4	3.6	6.1	5.5	3.8
Central							
Prior	0.0	5.0	5.0	10.0	20.0	50.0	10.0
Experts	0.0	0.9	4.5	19.8	19.8	12.7	42.2
Posterior	0.0	4.2	4.5	9.1	19.1	51.7	11.5
t-value	0.0	4.4	4.3	6.8	10.0	21.0	7.3
West							
Prior	11.8	23.5	35.3	11.8	5.9	5.9	5.9
Experts	2.3	5.9	7.6	16.3	22.3	21.3	24.3
Posterior	2.6	10.0	27.0	15.4	10.9	13.5	20.6
t-value	1.5	2.3	3.1	2.0	1.4	1.6	1.7

Table 32. Loss of OP, Year 1, Change in Yield, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	8.8	11.8	17.6	29.4	14.7	11.8	5.9
Experts	8.6	13.3	16.7	18.4	11.6	22.6	9.0
Posterior	7.3	10.5	16.8	29.9	15.7	13.1	6.8
t-value	6.3	7.6	10.0	14.6	9.6	8.5	6.3
Central							
Prior	4.1	5.3	6.5	7.6	11.8	52.9	11.8
Experts	24.3	17.3	25.5	12.6	12.6	6.8	0.9
Posterior	6.7	7.5	8.5	9.3	13.1	47.6	7.4
t-value	4.0	4.3	4.6	5.1	6.1	15.7	5.0
West							
Prior	2.9	5.9	8.8	11.8	11.8	41.2	17.6
Experts	9.3	12.3	13.3	22.3	15.6	26.3	0.9
Posterior	8.2	11.8	13.7	15.1	12.9	30.9	7.4
t-value	1.9	2.8	3.3	3.9	3.6	6.9	3.7

Table 33. Loss of OP, Year 1, Change in Allocation to Fresh, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
Prior	11.8	23.5	29.4	11.8	8.8	8.8	5.9
Experts	22.7	10.3	15.3	12.6	8.4	28.8	1.8
Posterior	10.5	22.5	29.5	12.1	9.3	9.5	6.5
t-value	3.5	5.3	6.2	3.7	3.1	3.1	2.6
Central							
Prior	10.0	30.0	30.0	15.0	10.0	5.0	0.0
Experts	39.9	26.9	24.5	5.7	2.1	0.9	0.0
Posterior	13.2	33.2	29.0	13.1	8.0	3.5	0.0
t-value	8.7	16.5	15.3	9.5	7.7	4.9	0.0
West							
Prior	2.9	8.8	11.8	17.6	29.4	17.6	11.8
Experts	10.9	15.3	16.0	15.6	14.3	22.0	5.9
Posterior	5.6	12.9	14.6	19.6	27.0	13.4	6.9
t-value	2.1	3.8	4.4	5.3	6.9	5.1	3.9

Table 34. Loss of APM, Year 5, Change in Cost, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	11.8	29.4	23.5	11.8	8.8
Experts	2.2	40.9	13.5	13.8	10.7	5.6	13.4
Posterior	9.2	11.7	13.9	29.5	20.7	9.0	6.0
t-value	2.0	2.4	2.7	4.7	3.9	2.4	2.1
Central							
Prior	10.0	50.0	20.0	10.0	5.0	5.0	0.0
Experts	15.1	24.5	18.6	15.1	15.1	11.6	0.0
Posterior	8.8	48.5	20.7	10.7	5.5	5.8	0.0
t-value	11.5	35.2	17.9	12.5	9.1	9.4	0.0
West							
Prior	10.0	10.0	10.0	30.0	20.0	15.0	5.0
Experts	2.0	5.2	9.4	17.1	20.0	26.2	20.0
Posterior	4.2	5.9	6.9	25.6	23.1	22.7	11.6
t-value	2.7	3.0	3.0	5.6	4.9	4.6	2.5

Table 35. Loss of APM, Year 5, Change in Yield, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
Experts	4.8	3.7	9.5	15.3	16.6	48.3	1.8
Posterior	3.0	5.5	13.0	32.3	21.2	13.6	11.3
t-value	1.4	1.7	2.5	4.1	2.8	2.0	1.7
Central							
Prior	5.7	6.3	6.8	7.4	11.4	51.1	11.4
Experts	3.3	3.3	7.9	26.6	12.6	36.0	10.3
Posterior	6.0	6.5	7.0	7.6	11.6	50.6	10.7
t-value	8.7	8.9	9.3	9.6	12.4	32.5	11.0
West							
Prior	5.0	6.0	9.0	10.0	20.0	30.0	20.0
Experts	7.4	8.8	8.8	10.6	15.7	44.8	3.8
Posterior	6.8	7.5	10.6	11.2	20.7	27.9	15.3
t-value	3.8	4.2	5.2	5.6	8.1	10.0	7.1

Table 36. Loss of APM, Year 5, Change in Allocation to Fresh, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	8.8	17.6	29.4	17.6	11.8	8.8	5.9
Experts	15.3	2.5	5.2	6.8	14.3	52.6	3.3
Posterior	4.6	11.8	24.7	18.5	15.1	13.6	11.6
t-value	1.4	2.1	3.1	2.4	2.0	1.8	1.4
Central							
Prior	5.9	11.8	35.3	17.6	11.8	8.8	8.8
Experts	3.3	13.8	24.3	15.0	22.0	11.4	10.3
Posterior	5.4	11.2	34.8	17.9	12.1	9.2	9.4
t-value	14.4	20.9	45.8	30.9	24.0	21.5	22.7
West							
Prior	5.9	5.9	5.9	5.9	17.6	47.1	11.8
Experts	5.6	6.3	6.6	8.3	10.3	52.0	10.9
Posterior	5.6	5.8	5.8	5.8	17.7	47.6	11.8
t-value	7.6	7.8	8.1	8.2	14.6	30.5	11.4

Table 37. Loss of OP, Year 5, Change in Cost, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	8.8	11.8	11.8	35.3	17.6
Experts	2.5	12.2	7.6	13.8	12.2	8.3	43.4
Posterior	4.2	6.9	7.5	10.7	11.2	37.1	22.5
t-value	2.5	3.2	3.2	3.7	3.8	8.1	5.3
Central							
Prior	5.9	8.8	8.8	11.8	17.6	29.4	17.6
Experts	5.6	15.0	5.6	0.9	5.6	12.6	54.7
Posterior	4.7	7.7	8.1	11.1	17.3	30.8	20.4
t-value	5.6	6.8	7.4	8.6	10.7	16.6	11.9
West							
Prior	11.8	11.8	17.6	29.4	11.8	11.8	5.9
Experts	1.6	2.9	4.3	8.9	16.0	24.0	42.3
Posterior	2.2	3.9	8.4	22.4	15.5	23.3	24.3
t-value	1.1	1.3	1.7	2.4	1.6	1.9	1.6

Table 38. Loss of OP, Year 5, Change in Yield, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	5.9	8.8	17.6	35.3	17.6	8.8	5.9
Experts	11.1	13.7	12.0	19.6	10.7	29.0	3.9
Posterior	5.5	8.5	17.4	35.2	17.9	9.3	6.2
t-value	2.8	3.6	5.3	8.4	5.4	3.6	3.0
Central							
Prior	5.0	10.0	15.0	40.0	15.0	10.0	5.0
Experts	16.5	30.5	32.1	13.4	5.6	0.9	0.9
Posterior	6.6	11.9	16.7	39.7	13.3	8.2	3.7
t-value	7.6	10.6	13.2	24.8	12.5	9.4	6.1
West							
Prior	4.0	6.0	20.0	40.0	20.0	6.0	4.0
Experts	12.1	16.8	11.0	15.3	18.5	25.0	1.3
Posterior	4.8	6.7	20.1	38.8	19.5	6.1	4.1
t-value	1.4	1.7	3.6	5.7	3.6	1.8	1.4

Table 39. Loss of OP, Year 5, Change in Allocation to Fresh, *SPR* = 0.09

	I	II	III	IV	V	VI	VII
East							
Prior	17.6	35.3	14.7	11.8	8.8	8.8	2.9
Experts	12.8	17.9	16.7	9.9	12.4	26.4	3.9
Posterior	11.8	30.6	15.6	13.4	11.1	12.4	5.1
t-value	5.4	9.3	5.4	5.0	4.4	4.5	2.8
Central							
Prior	17.6	35.3	11.8	11.8	8.8	8.8	5.9
Experts	43.0	19.6	7.9	3.3	0.9	10.3	15.0
Posterior	19.0	36.0	11.6	11.4	8.5	8.2	5.3
t-value	13.3	21.6	10.8	10.7	9.0	9.2	7.2
West							
Prior	8.8	8.8	17.6	29.4	17.6	11.8	5.9
Experts	8.6	12.6	21.6	16.3	11.9	21.3	7.6
Posterior	8.2	8.4	17.4	29.5	18.2	12.2	6.2
t-value	4.7	5.1	7.3	10.9	7.9	6.2	4.4

Table 40. Distribution of Marginal Cost Changes in $/lb., *SPR* = 0.13

	East	Central	West
APM Year 1			
Average	0.0024	0.0104	0.0065
Standard Dev.	0.0020	0.0059	0.0055
Skewness	1.3766	1.3312	2.0444
Minimum	-0.0006	0.0019	0.0000
1st Quartile	0.0012	0.0067	0.0029
Median	0.0020	0.0085	0.0045
3rd Quartile	0.0034	0.0132	0.0078
Maximum	0.0141	0.0316	0.0325
OP Year 1			
Average	0.0119	0.0184	0.0177
Standard Dev.	0.0053	0.0070	0.0085
Skewness	1.0511	0.8651	0.8260
Minimum	0.0032	0.0058	0.0063
1st Quartile	0.0077	0.0137	0.0108
Median	0.0105	0.0175	0.0159
3rd Quartile	0.0145	0.0222	0.0245
Maximum	0.0340	0.0409	0.0449
APM Year 5			
Average	0.0058	0.0089	0.0116
Standard Dev.	0.0039	0.0058	0.0079
Skewness	2.0138	1.4677	1.3553
Minimum	0.0002	0.0011	0.0013
1st Quartile	0.0032	0.0052	0.0058
Median	0.0046	0.0073	0.0089
3rd Quartile	0.0072	0.0110	0.0152
Maximum	0.0309	0.0344	0.0449
OP Year 5			
Average	0.0118	0.0161	0.0140
Standard Dev.	0.0052	0.0062	0.0066
Skewness	1.0418	0.8749	1.3680
Minimum	0.0026	0.0044	0.0040
1st Quartile	0.0077	0.0109	0.0094
Median	0.0110	0.0150	0.0123
3rd Quartile	0.0145	0.0193	0.0173
Maximum	0.0362	0.0409	0.0449

Table 41. Distribution of Marginal Cost Changes in $/lb., *SPR* = 0.09

	East	Central	West
APM Year 1			
Average	0.0029	0.0092	0.0085
Standard Dev.	0.0022	0.0054	0.0070
Skewness	1.3041	1.5507	1.6471
Minimum	-0.0006	0.0019	0.0006
1st Quartile	0.0013	0.0052	0.0040
Median	0.0022	0.0070	0.0058
3rd Quartile	0.0036	0.0112	0.0100
Maximum	0.0141	0.0316	0.0425
OP Year 1			
Average	0.0127	0.0158	0.0124
Standard Dev.	0.0060	0.0064	0.0072
Skewness	1.0510	0.9995	1.0760
Minimum	0.0032	0.0034	0.0023
1st Quartile	0.0082	0.0119	0.0070
Median	0.0114	0.0148	0.0100
3rd Quartile	0.0168	0.0191	0.0162
Maximum	0.0340	0.0409	0.0416
APM Year 5			
Average	0.0082	0.0090	0.0101
Standard Dev.	0.0045	0.0057	0.0075
Skewness	1.3534	1.4297	1.6185
Minimum	0.0012	0.0011	0.0019
1st Quartile	0.0048	0.0052	0.0050
Median	0.0068	0.0069	0.0076
3rd Quartile	0.0105	0.0105	0.0128
Maximum	0.0269	0.0336	0.0434
OP Year 5			
Average	0.0121	0.0153	0.0124
Standard Dev.	0.0055	0.0062	0.0066
Skewness	1.1114	0.9466	1.6164
Minimum	0.0026	0.0044	0.0037
1st Quartile	0.0078	0.0109	0.0080
Median	0.0114	0.0138	0.0107
3rd Quartile	0.0148	0.0192	0.0144
Maximum	0.0340	0.0379	0.0434

Table 42. Statistics of the Distribution of Economic Surplus Changes in $ mill., *SPR* = 0.13

	Short Run				Long Run			
	APM	OP τ =0	OP τ =1.25%	OP τ =2.5%	APM	OP τ =0	OP τ =1.25%	OP τ =2.5%
Average	-8.32	-24.65	-14.30	-2.05	-42.06	-60.62	-44.35	-28.62
Std. Dev.	5.80	20.22	20.91	20.92	26.16	34.95	36.48	36.65
Skewness	-2.03	-0.03	-0.12	-0.17	-1.38	-0.46	-0.27	-0.54
Minimum	-35.46	-85.79	-80.70	-79.02	-155.71	-213.85	-180.23	-170.45
1st Quartile	-9.56	-38.24	-28.23	-16.28	-54.57	-78.96	-67.68	-49.78
Median	-6.45	-24.42	-13.42	-1.22	-33.69	-58.38	-42.82	-25.33
3rd Quartile	-4.82	-10.28	-0.61	12.72	-22.85	-37.95	-18.29	-2.94
Maximum	-1.23	35.48	47.84	59.43	-8.45	60.47	55.89	63.72

Table 43. Statistics of the Distribution of Economic Surplus Changes in $ mill., *SPR* = 0.09

	Short Run				Long Run			
	APM	OP τ =0	OP τ =1.25%	OP τ =2.5%	APM	OP τ =0	OP τ =1.25%	OP τ =2.5%
Average	-10.39	-18.55	-7.49	3.99	-37.96	-53.97	-38.12	-23.20
Std. Dev.	7.34	20.44	20.16	20.45	24.78	35.13	37.06	36.68
Skewness	-1.63	-0.07	-0.21	0.10	-1.62	-0.55	-0.53	0.48
Minimum	-46.25	-95.38	-86.51	-67.11	-148.79	-180.33	-175.99	-158.12
1st Quartile	-12.15	-31.78	-21.17	-8.86	-48.05	-74.90	-58.84	-43.70
Median	-7.52	-19.06	-6.36	4.47	-29.24	-49.90	-34.53	-20.43
3rd Quartile	-5.43	-4.93	5.57	18.23	-21.17	-30.25	-13.83	0.94
Maximum	-1.85	42.89	56.46	71.26	-9.37	50.16	62.62	72.71

Table 44. Change in WTP ~ N(0,0.0004), *SPR* = 0.13[a]

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.00	0.20	-14.91	-14.91	0.05	0.15	-7.45	-7.45
0.00	0.20	-22.25	-17.50	0.09	0.11	-7.16	-7.72
0.05	0.15	-24.50	-20.55	0.05	0.15	-11.32	-8.59
0.07	0.13	-25.65	-22.90	0.07	0.14	-13.78	-9.68
0.13	0.08	-22.90	-24.24	0.07	0.13	-16.19	-11.00
0.15	0.05	-18.58	-24.65	0.11	0.09	-15.24	-12.18
0.19	0.01	-11.32	-24.73	0.13	0.07	-13.17	-12.80
0.18	0.02	-3.80	-24.65	0.15	0.05	-9.06	-13.16
0.18	0.02	7.01	-24.38	0.18	0.03	-0.89	-13.18
0.05	0.15	0.00	-19.60	0.11	0.09	0.00	-11.84

[a] Negative test statistics suggest that the distribution after a ban on APM is preferred over the distribution after a ban on OPs in the FSD or SSD sense, respectively. The 0.01 critical value for the test is 3.29.

Table 45. Change in WTP ~ N(1.25%,0.0004), *SPR* = 0.13

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.00	0.20	-14.76	-14.76	0.09	0.12	-2.24	-2.24
0.05	0.15	-16.88	-15.97	0.08	0.12	-3.91	-2.66
0.07	0.13	-17.57	-17.32	0.07	0.13	-6.25	-3.51
0.12	0.09	-15.06	-18.07	0.09	0.11	-6.94	-4.32
0.15	0.05	-10.46	-18.22	0.11	0.09	-6.17	-4.86
0.17	0.03	-4.20	-18.11	0.13	0.07	-3.47	-5.05
0.18	0.02	3.51	-17.84	0.15	0.05	0.78	-4.94
0.17	0.03	11.74	-17.31	0.16	0.04	7.60	-4.59
0.10	0.11	14.91	-14.58	0.12	0.08	13.27	-3.74
0.00	0.20	0.00	-7.03	0.01	0.19	0.00	0.13

Table 46. Change in WTP ~ N(2.5%,0.0004), *SPR* = 0.13

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.05	0.16	-8.20	-8.20	0.12	0.08	2.68	2.68
0.08	0.12	-8.61	-8.69	0.10	0.10	1.68	2.62
0.13	0.07	-4.59	-8.75	0.10	0.10	1.37	2.51
0.16	0.04	1.37	-8.43	0.11	0.09	1.83	2.50
0.17	0.03	7.96	-7.97	0.13	0.07	4.29	2.65
0.18	0.02	15.43	-7.34	0.14	0.06	8.40	3.10
0.17	0.03	23.32	-6.31	0.15	0.05	13.57	3.73
0.06	0.14	22.36	-1.32	0.13	0.07	18.67	4.83
0.00	0.20	14.91	3.53	0.03	0.17	14.91	7.35
0.00	0.20	0.00	7.48	0.00	0.20	0.00	9.94

Table 47. Change in WTP ~ N(0,0.0004), *SPR* = 0.09

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.01	0.19	-13.71	-13.71	0.05	0.15	-7.75	-7.75
0.06	0.14	-14.87	-14.46	0.07	0.13	-9.06	-8.42
0.05	0.15	-17.66	-15.87	0.06	0.14	-11.81	-9.58
0.09	0.11	-17.53	-17.08	0.08	0.13	-13.33	-10.71
0.14	0.06	-13.77	-17.75	0.09	0.11	-14.22	-11.81
0.15	0.05	-9.31	-17.86	0.12	0.08	-12.60	-12.42
0.17	0.03	-3.42	-17.77	0.14	0.07	-10.05	-12.81
0.19	0.02	5.59	-17.52	0.16	0.04	-4.81	-12.88
0.15	0.05	14.91	-16.62	0.16	0.04	2.61	-12.71
0.00	0.20	0.00	-9.59	0.08	0.12	0.00	-10.65

Table 48. Change in WTP ~ N(1.25%,0.0004), *SPR* = 0.09

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.05	0.15	-7.53	-7.53	0.08	0.12	-2.39	-2.39
0.07	0.13	-8.50	-8.01	0.08	0.12	-4.02	-2.90
0.10	0.10	-7.61	-8.47	0.09	0.11	-4.88	-3.41
0.13	0.07	-4.29	-8.54	0.09	0.12	-5.93	-3.98
0.17	0.03	1.83	-8.25	0.12	0.08	-4.29	-4.24
0.17	0.03	8.49	-7.77	0.13	0.07	-2.01	-4.31
0.18	0.02	16.59	-7.18	0.15	0.05	2.59	-4.17
0.13	0.07	22.36	-5.13	0.15	0.05	8.61	-3.74
0.00	0.20	14.91	-0.76	0.12	0.08	14.91	-2.48
0.00	0.20	0.00	4.33	0.00	0.20	0.00	1.81

Table 49. Change in WTP ~ N(2.5%,0.0004), *SPR* = 0.09

Year 1				Year 5			
Cell Probabilities		Test Statistics		Cell Probabilities		Test Statistics	
APM	OP	FSD	SSD	APM	OP	FSD	SSD
0.10	0.10	-0.60	-0.60	0.11	0.09	1.34	1.34
0.12	0.08	1.34	-0.27	0.11	0.09	1.90	1.55
0.15	0.05	5.76	0.44	0.09	0.11	0.68	1.58
0.16	0.04	10.86	1.21	0.13	0.07	3.38	1.71
0.18	0.02	17.71	2.13	0.13	0.07	6.08	2.10
0.18	0.02	25.01	3.15	0.16	0.05	11.23	2.65
0.13	0.07	29.28	7.14	0.14	0.06	16.30	3.49
0.00	0.20	22.36	13.16	0.12	0.08	21.35	5.08
0.00	0.20	14.91	15.97	0.01	0.19	14.91	8.11
0.00	0.20	0.00	17.57	0.00	0.20	0.00	10.86

Appendix 3A: A Note on the Correlation Structure

This appendix discusses a particular form of $\pi(\theta \mid \theta_i^k = j)$. Although we use a more general form in the calculation of the posterior, we find that this exposition aids in understanding the choice of the correlation coefficient. We choose $\pi(\theta \mid \theta_i^k = j)$ to be a linear combination of the S's opinion and the expert's opinion for each interval.

Suppose S reports his prior in the same form as the experts, i.e., as probabilities over the same partition θ^k as

$$\rho^k = \{(\rho_1^k, \rho_2^k, \ldots, \rho_K^k) : \rho_j^k = \text{Prob}(\theta^k = j), j = 1, \ldots, K, \sum_j \rho_j^k = 1\}.$$

Let $\pi(\theta \mid \theta_i^k = j) = b\begin{bmatrix}\rho_1^k & \rho_2^k & \cdots & \rho_K^k\end{bmatrix}^T + (1-b)\mathbf{1}_j$ where $\mathbf{1}_j$ is a $K \times 1$ vector of zeros with a one in the j-th entry and b is a positive constant, $b \in (0,1)$. Then the joint distribution of π that is consistent with the prior ρ^k and the expectation of the expert's opinion μ^k is

$$\pi(\theta^k, \theta_i^k) = b\begin{bmatrix}\rho_1^k \\ \rho_2^k \\ \vdots \\ \rho_K^k\end{bmatrix}\begin{bmatrix}\mu_1^k & \mu_2^k & \cdots & \mu_K^k\end{bmatrix} + (1-b)\begin{bmatrix}\mu_1^k & 0 & 0 & 0 \\ 0 & \mu_2^k & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \mu_K^k\end{bmatrix}.$$

If we choose $\mu^k = \rho^k$ for all experts i, then $E[\theta^k] = E[\theta_i^k]$ and $Var(\theta^k) = Var(\theta_i^k)$. The second moment of $\pi(\theta^k, \theta_i^k)$ can be calculated as

$$E\left[\theta^k\theta_i^k\right]=\begin{pmatrix}1 & 2 & \cdots & K\end{pmatrix}\pi\left(\theta^k\theta_i^k\right)\begin{pmatrix}1\\2\\\vdots\\K\end{pmatrix}$$

$$=\begin{pmatrix}1 & 2 & \cdots & K\end{pmatrix}\begin{bmatrix}1\cdot(1-b)\mu_1+b\rho_1(1\mu_1+2\mu_2+\cdots K\mu_K)\\2\cdot(1-b)\mu_2+b\rho_2(1\mu_1+2\mu_2+\cdots K\mu_K)\\\vdots\\K\cdot(1-b)\mu_K+b\rho_K(1\mu_1+2\mu_2+\cdots K\mu_K)\end{bmatrix}$$

$$=\begin{pmatrix}1 & 2 & \cdots & K\end{pmatrix}\begin{bmatrix}1\cdot(1-b)\mu_1+b\rho_1E\left[\theta^k\right]\\2\cdot(1-b)\mu_2+b\rho_2E\left[\theta^k\right]\\\vdots\\K\cdot(1-b)\mu_K+b\rho_KE\left[\theta^k\right]\end{bmatrix}$$

$$=(1-b)E\left[(\theta^k)^2\right]+b\left(E\left[\theta^k\right]\right)^2,$$

so that $Cov(\theta^k,\theta_i^k)=E\left[\theta^k\theta_i^k\right]-\left(E\left[\theta^k\right]\right)^2=(1-b)E\left[(\theta^k)^2\right]+b\left(E\left[\theta^k\right]\right)^2-\left(E\left[\theta^k\right]\right)^2$ $=(1-b)Var\left(\theta^k\right)$ and the correlation results as $\text{Corr}(\theta^k,\theta_i^k)=1-b$. Hence the smaller the correlation that we choose, the larger the influence of the prior in the mixture.

We elaborate further on this last point by explicitly calculating the formula of the posterior for this particular case. The posterior for one expert is

$$p_i^*(\theta^k=j\mid \text{S},H_i)=b\rho_j^k+(1-b)g_{ij}$$

and using the law of conditional probability

$$\text{Prob}(H_i\mid\theta^k=j)=\left(b+(1-b)\frac{g_{ij}}{\rho_j^k}\right)\text{Prob}(H_i).$$

Combining the assessment of several experts

$$\begin{aligned}
\text{Prob}(\theta^k = j \mid \text{S}, H_1, H_2, \ldots, H_K) &\propto \rho_j^k \prod_N \left(b + (1-b)\frac{g_{ij}}{\rho_j^k} \right) \\
&= b^N \rho_j^k + (1-b)b^{N-1}\sum_{i=1}^{N} g_{ij} \\
&\quad + (1-b)^2 b^{N-2}(\rho_j^k)^{-1}\sum_{i=1}^{N-1}\prod_{l=i+1}^{N} g_{ij}g_{lj} \qquad (2A.1) \\
&\quad + (1-b)^3 b^{N-3}(\rho_j^k)^{-2}\sum_{i=1}^{N-2}\prod_{l=i+1}^{N-1}\prod_{m=l+1}^{N} g_{ij}g_{lj}g_{mj} \\
&\quad + \cdots + (1-b)^N(\rho_j^k)^{-(N-1)}\prod_{i=1}^{N} g_{ij}.
\end{aligned}$$

Equation (2A.1) shows that a larger b leads to a higher weight on S's opinion. It is evident that the weighing of experts versus S will depend on the number of experts in the assessment. The influence of the correlation coefficient will hence depend on the number of expert opinions to be combined.

Appendix 3B: Expert Survey Instrument

Establishing Confidence in Expert Opinion in Pesticide Benefit Assessments

This questionnaire consists of two parts: one will ask you about the impact of a removal of azinphos-methyl (Guthion), and the other will ask you about the impact of a removal of the entire group of organophosphorus pesticides. In each part we will ask you about immediate (short-run) impacts and long-run impacts.

We are surveying U.S. apple production by region. You have been identified as an expert for the region West (CA, OR, WA). We summarized some key facts about apple production in the West of the United States.

3-Year-Averages (1994-1995-1996) for Region West (CA, OR, WA):

	Acreage (acres)	Yield (lb.)	Total Production (mill. lb.)	Fresh Utilization (%)
California	35,367	26,433	933	35
Oregon	8,600	18,600	160	74
Washington	152,667	35,400	5,400	72
West	196,633	33,021	6,493	67

The following page gives you information about the organophosphorus insecticide use in the region.

We urge you to complete all of the questions since this data will help to improve the confidence in expert opinion and help to understand the uncertainty involved for apple producers when certain pesticides become unavailable.

Insecticide Use Data for Apples
(Summarized from USDA-NASS "Agricultural Chemical Usage: Fruit Summary"; data collected in 1995 and 1993)

Mean taken from 1993 & 95 Survey	Trade Name	% of bearing acres treated	mean no. of applications	lb a.i. per acre per application	rate of formulated insecticide per acre	% of bearing acres treated	mean no. of applications	lb a.i. per acre per application	rate of formulated insecticide per acre
			WEST				**California**		
Azinphos-methyl	Guthion	80.4	2.70	0.96	2.60	48.0	2.25	1.04	2.32
Chlorpyrifos	Lorsban	75.8	1.55	1.58	2.35	45.0	1.95	1.31	2.55
Diazinon		10.8	1.63	1.50	3.17	47.5	1.75	1.41	2.16
Dimethoate	Cygon	20.1	1.38	1.40	1.02	20.0	1.90	0.53	1.00
Malathion	Malathon	21.3	2.95	0.78	1.52				
Methyl Parathion	Penncap-M	19.4	1.53	1.47	2.30	7.5	1.35	1.35	1.82
Mevinphos	Phosdrin	27.7	1.10	0.38	0.43				
Phosmet	Imidan	13.1	1.75	2.30	3.44	21.5	1.80	2.22	3.96
Phosphamidon	Dimecron	30.0	1.43	0.54	0.77				
			Oregon				**Washington**		
Azinphos-methyl	Guthion	88.0	2.5	0.90	2.33	87.5	3.30	0.95	3.16
Chlorpyrifos	Lorsban	83.0	1.4	1.72	2.31	82.5	1.30	1.73	2.19
Diazinon		6.0	1.95	1.39	5.32	2.5	1.20	1.69	2.03
Dimethoate	Cygon	31.0	1.15	1.82	1.05	19.5	1.10	1.86	1.03
Malathion	Malathon	16.5	2.3	0.69	1.55	26.5	3.60	0.87	1.50
Methyl Parathion	Penncap-M	31.5	2.05	1.67	3.44	21.5	1.20	1.39	1.65
Mevinphos	Phosdrin					28.0	1.10	0.38	0.43
Phosmet	Imidan	23.5	1.7	2.16	3.75	10.5	1.75	2.53	2.61
Phosphamidon	Dimecron	12.0	1.45	0.51	0.75	38.0	1.40	0.57	0.79

Removal of Azinphos-methyl (Guthion)

SHORT RUN

Q1-Q40. This section of questions asks you to provide your own probability assessment of the short-run impacts of the removal of azinphos-methyl. By short run, we mean the impacts on apple production in the first year after a hypothetical removal of azinphos-methyl. Your assignment of probabilities will provide information about how confident you are concerning changes to the apple industry resulting from a ban. If you feel very certain about what will happen, you will assign a high probability to the interval that contains your expected change and low probabilities to the other intervals. However, if you have low confidence in your assessment, you might want to assign relatively high probability to several intervals. When doing so remember that some intervals are not as wide as others.

For example, suppose that average yield in your state is 25,000 lb./acre. You think that following a ban of the pesticide in question, the average yield might possibly increase by more than 0.5 %; but, in your view, this has only a 5 percent probability or chance of actually occurring. For a change in yield of +/- 0.5 %, you assign a probability of 35%; for a yield change between 0.5 % and 1 %, you assign a probability of 40%; for a yield decrease between 1 % and 3 % you assign 20 % probability and for a yield decrease of more than 3 %, you assign a probability of zero. Your responses are entered in the following way:

	Probabilities
1. Increase by more than 0.5 %	5%
2. Increase or decrease by less than 0.5 %	35%
3. Decrease by between 0.5 % and 1 %	40%
4. Decrease by between 1 % and 3 %	20%
5. Decrease by between 3 % and 5 %	0%
	100%

Please note that the sum of the probabilities should equal 100%. Also, probabilities for no change are to be included in the increase or decrease by less than 0.5 %. *When answering questions concerning short-run impacts, please assume that prices for apples, pesticides etc. will stay constant.*

Please remember that economic considerations are important in the pest management decisions of a commercial grower. Therefore, he/she will not necessarily choose the same level of pest control.

Q1. Budgets of apple production in your region show that the total pre-harvest cost of apple production is **1300 $/acre/year**. Insect pest control costs (including insecticides and miticides) are given at **170 $/acre/year**. Indicate the *average percent change (+/-) of* ***total cost in apple production in the next year*** if azinphos-methyl is no longer available.

______________ %.

Q2-Q8. If azinphos-methyl is no longer available, what are the probabilities that in the first year *average pest control cost of apple production* will

		Probabilities
Q2.	Decrease by more than 0.5 %	________ %
Q3.	Decrease or increase by less than 0.5 %	________ %
Q4.	Increase by between 0.5 % and 1 %	________ %
Q5.	Increase by between 1 % and 3 %	________ %
Q6.	Increase by between 3 % and 5 %	________ %
Q7.	Increase by between 5 % and 10 %	________ %
Q8.	Increase by more than 10 %	________ %
		100 %

Q9. If azinphos-methyl is no longer available, what change (+/-) *in average regional apple yield* do you expect in the first year?

____________ %.

Q10-Q16. If azinphos-methyl is no longer available, what are the probabilities that in the first year *average regional apple yield* will

		Probabilities
Q10.	Increase by more than 0.5 %	________ %
Q11.	Increase or decrease by less than 0.5 %	________ %
Q12.	Decrease by between 0.5 % and 1 %	________ %
Q13.	Decrease by between 1 % and 3%	________ %
Q14.	Decrease by between 3 % and 5%	________ %
Q15.	Decrease by between 5 % and 10 %	________ %
Q16.	Decrease by more than 10 %	________ %
		100 %

Q17. If azinphos-methyl is no longer available, what change (+/-) in *regional apple acreage* do you expect in the first year?

__________ %.

Q18-Q24. If azinphos-methyl is no longer available, what are the probabilities that in the first year the *regional apple acreage* will

		Probabilities
Q18.	Increase by more than 0.5 %	________ %
Q19.	Increase or decrease by less than 0.5 %	________ %
Q20.	Decrease by between 0.5 % and 1 %	________ %
Q21.	Decrease by between 1 % and 3 %	________ %
Q22.	Decrease by between 3 % and 5 %	________ %
Q23.	Decrease by between 5 % and 10 %	________ %
Q24.	Decrease by more than 10 %	________ %
		100 %

Q25. If azinphos-methyl is no longer available, what change (+/-) in the *regional total apple production*[1] do you expect in the first year?

__________ %.

Q26-Q32. If azinphos-methyl is no longer available, what are the probabilities that in the first year the *regional total apple production* will

		Probabilities
Q26.	Increase by more than 0.5 %	________ %
Q27.	Increase or decrease by less than 0.5 %	________ %
Q28.	Decrease by between 0.5 % and 1 %	________ %
Q29.	Decrease by between 1 % and 3 %	________ %
Q30.	Decrease by between 3 % and 5 %	________ %
Q31.	Decrease by between 5 % and 10 %	________ %
Q32.	Decrease by more than 10 %	________ %
		100 %

[1] Total production is defined as yield times acreage in a region. We need to ask this question in addition to the two preceeding ones in order to deal with the dependence between yield and acreage changes.

Q33. If azinphos-methyl is no longer available, what change (+/-) in the *regional share of apples marketed as fresh* do you expect in the first year?

_________ %.

Q34-Q40. If azinphos-methyl is no longer available, what are the probabilities that in the first year the *regional share of apples marketed as fresh* will

		Probabilities
Q34.	Increase by more than 0.5 %	________ %
Q35.	Increase or decrease by less than 0.5 %	________ %
Q36.	Decrease by between 0.5 % and 1 %	________ %
Q37.	Decrease by between 1 % and 3 %	________ %
Q38.	Decrease by between 3 % and 5 %	________ %
Q39.	Decrease by between 5 % and 10 %	________ %
Q40.	Decrease by more than 10 %	________ %
		100 %

LONG RUN

Q41-Q80. Now you will be asked for the impacts in the distant future, five years from now, of the removal of azinphos-methyl. It is important to consider long-run changes since apples are a perennial crop. Therefore, the full impact of pesticide regulations might not be seen in the first year after the policy is in place, but over time, apple growers might make further adjustments to accommodate for the change. We chose the time frame of five years because predicting in a longer time frame may be too difficult. Again, *assume that prices stay constant.*

The difference between your assessment here and your response to the short-run questions is that at the end of five years apple producers are more flexible in changing their production program than in the shorter one-year framework. For instance, an apple producer might decide to substitute another pest control means for the banned pesticide in the short run, but might adopt a comprehensive IPM method in the long run. Or a producer who continued production in the short run, because the orchards were already planted, might give up some apple acreage when it comes to the decision to replant the orchards.

Also assume in your assessment that technology might change; that is, new pesticides or biological control methods might be developed since producers now have the incentive to find other methods to control the pest. We ask you for the best prediction you can give of how production quantity, quality, and costs change when most of the inputs are variable.

Although you might think that there is too much uncertainty involved in your assessment and that there is no adequate experimental data to support your assessment, we believe that experts like you, who have worked in apple production for a long period of time, can give the most informed opinion possible. But if you are concerned that you have low confidence in your assessment, you can adjust for this by giving the probability distribution of the expected change a large spread.

In summary, in your assessment of the long-run questions:

(i) List the changes you expect *5 years after the ban.*
(ii) Accommodate for the *higher flexibility of the apple producer* in production program adjustments.
(iii) Assume in general that *production might become more efficient* and that new and better methods and varieties might become known.
(iv) Include also that, if an important pesticide is banned, *producers and researchers might spend effort to find a suitable substitute*, which might decrease the impact on production.
(v) Assume that *prices for apples, pesticides etc. stay constant.*

Q41. List the *average change of total cost (+/-) in apple production in the next 5 years* if azinphos-methyl is no longer available. Remember that we are interested in the cost change to the profit-maximizing producer, and not in the cost change for maintaining the same level of pest control.

________________ %.

Q42-Q48. If azinphos-methyl is no longer available, what are the probabilities that *average cost of apple production* in 5 years will

		Probabilities
Q42.	Decrease by more than 0.5 %	______ %
Q43.	Decrease or increase by less than 0.5 %	______ %
Q44.	Increase by between 0.5 % and 1 %	______ %
Q45.	Increase by between 1 % and 3 %	______ %
Q46.	Increase by between 3 % and 5 %	______ %
Q47.	Increase by between 5 % and 10 %	______ %
Q48.	Increase by more than 10 %	______ %
		100 %

Q49. If azinphos-methyl is no longer available, what change (+/-) in *average regional apple yield* do you expect in 5 years from now?

________________ %.

Q50-Q56. If azinphos-methyl is no longer available, what are the probabilities that the *average regional apple yield* in 5 years will

		Probabilities
Q50.	Increase by more than 0.5 %	______ %
Q51.	Increase or decrease by less than 0.5 %	______ %
Q52.	Decrease by between 0.5 % and 1 %	______ %
Q53.	Decrease by between 1 % and 3 %	______ %
Q54.	Decrease by between 3 % and 5 %	______ %
Q55.	Decrease by between 5 % and 10 %	______ %
Q56.	Decrease by more than 10 %	______ %
		100 %

Q57. If azinphos-methyl is no longer available, what change (+/-) in *regional apple acreage* do you expect in 5 years from now?

_______________ %.

Q58-Q64. If azinphos-methyl is no longer available, what are the probabilities that in 5 years from now the *regional apple acreage* will

		Probabilities
Q58.	Increase by more than 0.5 %	________ %
Q59.	Increase or decrease by less than 0.5 %	________ %
Q60.	Decrease by between 0.5 % and 1 %	________ %
Q61.	Decrease by between 1 % and 3 %	________ %
Q62.	Decrease by between 3 % and 5 %	________ %
Q63.	Decrease by between 5 % and 10 %	________ %
Q64.	Decrease by more than 10 %	________ %
		100 %

Q65. If azinphos-methyl is no longer available, what change (+/-) in *regional total apple production* do you expect in 5 years from now?

_______________ %.

Q66-Q72. If azinphos-methyl is no longer available, what are the probabilities that 5 years from now the *regional total apple production* will

		Probabilities
Q66.	Increase by more than 0.5 %	________ %
Q67.	Increase or decrease by less than 0.5 %	________ %
Q68.	Decrease by between 0.5% and 1 %	________ %
Q69.	Decrease by between 1 % and 3 %	________ %
Q70.	Decrease by between 3 % and 5 %	________ %
Q71.	Decrease by between 5 % and 10 %	________ %
Q72.	Decrease by more than 10 %	________ %
		100 %

Q73. If azinphos-methyl is no longer available, what change (+/-) in *the regional share of apples marketed as fresh* do you expect in 5 years from now?

____________ %.

Q74-Q80. If azinphos-methyl is no longer available, what are the probabilities that in 5 years from now the *regional share of apples marketed as fresh* will

		Probabilities
Q74.	Increase by more than 0.5 %	________ %
Q75.	Increase or decrease by less than 0.5 %	________ %
Q76.	Decrease by between 0.5 % and 1 %	________ %
Q77.	Decrease by between 1 % and 3 %	________ %
Q78.	Decrease by between 3 % and 5 %	________ %
Q79.	Decrease by between 5 % and 10 %	________ %
Q80.	Decrease by more than 10 %	________ %
		100 %

Removal of All Organophosphorus Pesticides

SHORT RUN

Q81-Q120. This section of questions asks you to provide your own probability assessment of the short-run impacts of the removal of all organophosphorus pesticides. By short run, we mean the impacts on apple production in the first year after a hypothetical removal of all organophosphorus pesticides. Your assignment of probabilities will provide information about how confident you are concerning changes to the apple industry resulting from a ban.

If you feel very certain about what will happen, you will assign a high probability to the interval that contains your expected change and low probabilities to the other intervals. However, if you have low confidence in your assessment, you might want to assign relatively high probability to several intervals. When doing so remember that some intervals are not as wide as others.

The group of all organophosphorus pesticides includes:

Azinphos-methyl (Guthion),
Chlorpyrifos (Lorsban),
Diazinon (Diazinon),
Dimethoate (Cygon),
Malathion (Malathon)
Mevinphos (Phosdrin)
Methyl parathion (Penncap-M), and
Phosmet (Imidan)
Phosphamidon (Dimecron).

Please assume also that no new organophosphates will become available in the future.

The impacts of removing an entire group of pesticides from the market are important to consider in pesticide regulations, as this removal will cause growers to lose mutual substitutes for pest control at the same instant.

Please note again that the sum of the probabilities should equal 100%. *When answering questions concerning short-run impacts, please assume that prices will stay constant.*

Q81. Budgets of apple production in your region show that the total pre-harvest cost of apple production is **1300 $/acre.** Pest control costs are given at **170 $/acre.** Indicate the *average percent change (+/-) of* ***total cost*** *in apple production in the next year* if the group of all organophosphorus pesticides is no longer available.

__________ %.

Q82-Q88. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in the first year *average cost of apple production* will

		Probabilities
Q82.	Decrease by more than 0.5 %	_______ %
Q83.	Decrease or increase by less than 0.5 %	_______ %
Q84.	Increase by between 0.5 % and 1 %	_______ %
Q85.	Increase by between 1 % and 3 %	_______ %
Q86.	Increase by between 3 % and 5 %	_______ %
Q87.	Increase by between 5 % and 10 %	_______ %
Q88.	Increase by more than 10 %	_______ %
		100 %

Q89. If the group of all organophosphorus pesticides is no longer available, what change (+/-) *in average regional apple yield* do you expect in the first year?

__________ %.

Q90-Q96. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in the first year *average regional apple yield* will

		Probabilities
Q90.	Increase by more than 0.5 %	_______ %
Q91.	Increase or decrease by less than 0.5 %	_______ %
Q92.	Decrease by between 0.5 % and 1 %	_______ %
Q93.	Decrease by between 1 % and 3 %	_______ %
Q94.	Decrease by between 3 % and 5 %	_______ %
Q95.	Decrease by between 5 % and 10 %	_______ %
Q96.	Decrease by more than 10 %	_______ %
		100 %

Q97. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *regional apple acreage* do you expect in the first year?

__________ %.

Q98-Q104. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in the first year the *regional apple acreage* will

		Probabilities
Q98.	Increase by more than 0.5 %	________ %
Q99.	Increase or decrease by less than 0.5 %	________ %
Q100.	Decrease by between 0.5 % and 1 %	________ %
Q101.	Decrease by between 1 % and 3 %	________ %
Q102.	Decrease by between 3 % and 5 %	________ %
Q103.	Decrease by between 5 % and 10 %	________ %
Q104.	Decrease by more than 10 %	________ %
		100 %

Q105. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in the *regional total apple production* do you expect in the first year?

__________ %.

Q106-Q112. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in the first year the *regional total apple production* will

		Probabilities
Q106.	Increase by more than 0.5 %	________ %
Q107.	Increase or decrease by less than 0.5 %	________ %
Q108.	Decrease by between 0.5 % and 1 %	________ %
Q109.	Decrease by between 1 % and 3 %	________ %
Q110.	Decrease by between 3 % and 5 %	________ %
Q111.	Decrease by between 5 % and 10 %	________ %
Q112.	Decrease by more than 10 %	________ %
		100 %

Q113. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *regional share of apples marketed as fresh* do you expect in the first year?

________ %.

Q114-Q120. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in the first year the *regional share of apples marketed as fresh* will

	Probabilities
Q114. Increase by more than 0.5 %	________ %
Q115. Increase or decrease by less than 0.5 %	________ %
Q116. Decrease by between 0.5 % and 1 %	________ %
Q117 Decrease by between 1 % and 3 %	________ %
Q118 Decrease by between 3 % and 5 %	________ %
Q119 Decrease by between 5 % and 10 %	________ %
Q120. Decrease by more than 10 %	________ %
	100 %

LONG RUN

Q121-Q160. Now you will again be asked for the impacts in the distant future, five years from now, this time in the case of the removal of all organophosphorus pesticides. The same comments as in the last long run section apply.

In summary, in your assessment of the long-run questions:
(i) List the changes you expect *5 years after the ban.*
(ii) Accommodate for the *higher flexibility of the apple producer* in production program adjustments.
(iii) Assume in general that *production might become more efficient* and that new and better methods and varieties might become known.
(iv) Include also that, if an important pesticide is banned, *producers and researchers might spend effort to find a suitable substitute,* which might decrease the impact on production.
(v) Assume that *prices stay constant.*

Q121. List the *average change of total cost (+/-) in apple production in the next 5 years* if the group of all organophosphorus pesticides is no longer available. Remember that we are interested in the cost change to the commercial grower, and not in the cost change for maintaining the same level of pest control.

_______________ %.

Q122-Q128. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that *average total cost of apple production* in 5 years will

	Probabilities
Q122. Decrease by more than 0.5 %	________ %
Q123. Decrease or increase by less than 0.5 %	________ %
Q124. Increase by between 0.5 % and 1 %	________ %
Q125. Increase by between 1 % and 3 %	________ %
Q126. Increase by between 3 % and 5 %	________ %
Q127. Increase by between 5 % and 10 %	________ %
Q128. Increase by more than 10 %	________ %
	100 %

Q129. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *average regional apple yield* do you expect in 5 years from now?

_______________ %.

Q130-Q136. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that the *average regional apple yield* in 5 years will

	Probabilities
Q130. Increase by more than 0.5 %	________ %
Q131. Increase or decrease by less than 0.5 %	________ %
Q132. Decrease by between 0.5 % and 1 %	________ %
Q133. Decrease by between 1 % and 3 %	________ %
Q134. Decrease by between 3 % and 5 %	________ %
Q135. Decrease by between 5 % and 10 %	________ %
Q136. Decrease by more than 10 %	________ %
	100 %

Q137. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *regional apple acreage* do you expect in 5 years from now?

_______________ %.

Q138-Q144. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in 5 years from now the *regional apple acreage* will

	Probabilities
Q138. Increase by more than 0.5 %	________ %
Q139. Increase or decrease by less than 0.5 %	________ %
Q140. Decrease by between 0.5 % and 1 %	________ %
Q141. Decrease by between 1 % and 3 %	________ %
Q142. Decrease by between 3 % and 5 %	________ %
Q143. Decrease by between 5 % and 10 %	________ %
Q144. Decrease by more than 10 %	________ %
	100 %

Q145. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *regional total apple production* do you expect in five years from now?

_______________ %.

Q146-Q152. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that 5 years from now the *regional total apple production* will

	Probabilities
Q146. Increase by more than 0.5 %	_______ %
Q147. Increase or decrease by less than 0.5 %	_______ %
Q148. Decrease by between 0.5 % and 1 %	_______ %
Q149. Decrease by between 1 % and 3 %	_______ %
Q150. Decrease by between 3 % and 5 %	_______ %
Q151. Decrease by between 5 % and 10 %	_______ %
Q152. Decrease by more than 10 %	_______ %
	100 %

Q153. If the group of all organophosphorus pesticides is no longer available, what change (+/-) in *regional share of apples marketed as fresh* do you expect in 5 years from now?

_____________ %.

Q154-Q160. If the group of all organophosphorus pesticides is no longer available, what are the probabilities that in 5 years from now the *regional share of apples marketed as fresh* will

	Probabilities
Q154. Increase by more than 0.5 %	_______ %
Q155. Increase or decrease by less than 0.5 %	_______ %
Q156. Decrease by between 0.5 % and 1 %	_______ %
Q157. Decrease by between 1 % and 3 %	_______ %
Q158. Decrease by between 3% and 5 %	_______ %
Q159. Decrease by between 5 % and 10 %	_______ %
Q160. Decrease by more than 10 %	_______ %
	100 %

CHAPTER 4. AN EQUILIBRIUM ANALYSIS OF ANTIBIOTICS USE AND REPLANTING DECISIONS IN APPLE PRODUCTION

A paper to be submitted to the American Journal of Agricultural Economics

Jutta Roosen [1,2]

Abstract

Antibiotics are used in fruit production to control fire blight, a bacterial disease of fruit trees that leads to yield losses and eventually to tree death. Because of fears about the development of widespread resistance from excessive antibiotics use, scientists and public health officials are becoming increasingly concerned about antibiotics use in agriculture. We develop a framework that allows estimation of the impacts a ban on antibiotics would have on the apple industry, and we formulate a model of investment in orchard replanting as a function of disease risk. We embed the individual grower's decision to replant into an industry equilibrium in order to facilitate a welfare analysis. Welfare impacts of survival probability changes after a ban on antibiotics are estimated.

Introduction

Antibiotics are used in fruit production to control fire blight, an economically important bacterial disease of apples, pears, and other plants of the rose family *(rosacea)* that is caused by the bacterium *Erwinia amylovora*. Fire blight differs from other common plant diseases in that it not only affects yield and quality of the current crop, but also leads to significantly lower productivity of plants for several years. Severe infections can lead to tree death, especially in younger trees (van der Zwet and Beer). Outbreaks of fire blight are sporadic, but losses can be devastating if the disease becomes epidemic and whole regions are infected.

Currently 35.8% of U.S. apple acreage is planted to fire blight susceptible varieties (Rosenberger). This percentage is increasing as many of the new varieties such as Fuji and

Pink Lady are much more susceptible than the common older varieties such as Red or Golden Delicious. This development is reinforced by a similar trend towards planting rootstocks with high susceptibility to fire blight (van der Zwet and Beer). Plant pathologists have consistently reported fire blight as a disease of high importance in apple and pear orchards (van der Zwet and Beer). In 1991, a severe fire blight outbreak in Michigan caused losses estimated at $3.8 million dollars (van der Zwet and Beer). If antibiotics are lost for fire blight control, experts conjecture that apple acreage would decrease by 8.7% in the next five years and annual yield would decrease by 8% (Rosenberger). The principal antibiotics in a fire blight control program are streptomycin and oxytetracycline. Copper compounds are available as an alternative means of control; however, copper compounds are much less effective and more phytotoxic than antibiotics.

The possibility of losing access to antibiotics as a means of control arises because their use in agriculture is currently debated very controversially due to public health concerns over the risk of resistance development (Witte; Grady). By now at least three bacterial species capable of causing life-threatening illnesses (*Enterococcus faecalis, Mycobacterium tuberculosis,* and *Pseudomonas aeruginosa)* have developed resistance to all antibiotics available (Levy 1998).[3] The increase in antibiotic resistance that Levy calls an "international public health nightmare" has triggered entities such as the World Health Organization and the Center for Disease Control and Prevention to convene working groups and task forces.

Bacteria can store their resistance genes in so-called plasmoids, a cell structure that can be transferred between bacteria. Especially if bacteria are of common families, it is likely that resistance features can be transferred. *Erwinia* for instance belongs to the family of Enterobacteriaceae, the family that includes *Escherichia coli*, *Salmonella*, and *Shigella*, all of which are well known causes of foodborne diseases. Bacteria in this family can exchange genes among themselves. Although streptomycin, the antibiotic that is most used in fruit production, is no longer widely used in human health treatment, streptomycin resistance is often found in conjunction with other resistance determinants. Some *Erwinia amylovora* displaying multidrug resistance in transferable plasmoids have been isolated, and so the use of streptomycin increases the development of multidrug resistance (Levy 1992, p. 163).

It has been shown that people who are frequently exposed to antibiotics are at a higher risk to contract antibiotic resistant bacteria (Levy 1998). When applying antibiotics in aerosols to fruit trees, bacteria on the trees are killed, but lingering antibiotic residues can encourage the development of resistance. People can then acquire resistant bacteria through food consumption. Corpet showed that when humans are restricted to a diet of bacteria free foods, the number of resistant bacteria in their feces decreased 1000 fold. Levy (1992, p. 165) isolated 20,000 to 100,000 antibiotic resistant bacteria per gram of vegetable in a study carried out in Boston. The amount of resistant bacteria on food does not appear to be trivial.

These public health concerns put in question the future use of antibiotics for disease control in fruit production, and for instance in Italy antibiotics may no longer be used for fire blight control. A study of the implications of losing control over fire blight is furthermore of interest because of developments in apple production systems themselves because the fire blight bacterium has developed resistance to streptomycin in the Pacific Northwest (Smith). Growers have to rely on access to oxytetracycline for which an exceptional permission has to be obtained from the Environmental Protection Agency, and the industry is continuously at risk of not having sufficient means for blight control. This problem is aggravated by the fact that in recent years unusually warm spring weather conditions in the Northwest have led to an increase in the fire blight prevalence.

The objective of this paper is to estimate the importance of antibiotics in apple production systems and to this end, a model of orchard replanting that can incorporate the changes in orchard survival probabilities is developed. Existing models developed to estimate marginal-cost changes resulting from a regulation of pesticide use are not suitable for our case because marginal-cost changes in these models result only from changes in cost of production or from changes in yield (Lichtenberg, Parker, and Zilberman; Sunding). They do not incorporate risk and so do not offer a way to accommodate survival probability changes. Furthermore, there does not exist any model that analyzes the decision of orchard replanting depending on survival probability.

We first propose a model that includes the probability of an orchard being destroyed in any given year, and we apply it to study the optimal cycle of orchard planting and replanting. The analysis uses the concept of industry equilibrium similar to Silberberg or Appelbaum and Katz, and embeds choices of individual investors in a partial equilibrium model. This allows us to derive the price changes necessary to keep acreage in apple production, so that we can estimate welfare impacts of a change in the risk environment. We then study the model and its responses to changes in the market and physical environment using analytical and numerical tools. We estimate the welfare impacts of a ban on antibiotics in U.S. apple production, and the paper is concluded with a brief discussion.

The Model

Although several models exist to econometrically estimate the adjustments in orchard acreage (Elnagheeb and Florkowski; French, Minami, and King; Hartley, Nerlove, and

Peters; Knapp; Knapp and Konyar) or to model the replanting decision as a recursive dynamic programming problem (Gunter and Bender), to our knowledge there exists no model that analyses explicitly the optimal replanting decision of the individual orchard. We develop such a model using building on the existing literature in forestry economics (Hartman; Reed).

Site Value

In this section, we develop a Faustmann-type model (Clark, chapters 9.1 and 11.2) to analyze the decision to replant an orchard, where we explicitly model the probability that an orchard is destroyed at any given time. An orchard is planted at cost I, and can remain in production for several decades. At planting time, the basic orchard technology is chosen, including aspects such as variety, rootstock, irrigation, and planting density, and subsequently the production function has a very low elasticity of substitution with respect to variable input choices. To focus on the long-term planting decision, we model production as a Leontief technology that changes with orchard age t. The instantaneous revenue function can be described by

$$r(t) = p(t)y(t) - c(t) \tag{1}$$

where $p(t)$ is the price paid for the crop at time t, $y(t)$ is yield at time t, and $c(t)$ presents the cost of running the existing orchard.[4]

Times between successive orchard destructions are denoted as $X_1, X_2, \ldots,$ and can occur either because the orchard has been destroyed by disease or other adverse events or because it has been removed for economic considerations. Each period from planting to cutting of the orchard is described as an orchard cycle, and the duration of the n-th orchard cycle is X_n. Discounting forward the net returns of the orchard over its life cycle, the cumulative return is

$$R_n = \int_0^{X_n} r(t)\, e^{\delta(X_n - t)} dt = e^{\delta X_n} \int_0^{X_n} r(t)\, e^{-\delta t}\, dt . \tag{2}$$

The occurrence of destruction by fire blight or any other adverse event is modeled as a Poisson process with the intensity rate λ, so that the probability distribution of the random variables $\{X_n\}$ is

$$F_X(t) = \begin{cases} 1 - e^{-\lambda t}, & t < T \\ 1, & t \geq T \end{cases} \tag{3}$$

where $F_X(t)$ is the cumulative density function, i.e., for $n = 1, 2, \ldots,$ $F_X(t) = \text{Prob}(X_n \leq t)$. In (3), T is the time of planned replanting so that the planned replanting time T is the upper bound on orchard age. The destruction times are independent of each other and thus form a renewal process (Taylor and Karlin).[5]

To calculate the complete site value, we compute the discounted infinite return to the land, applying the discount rate δ, so that the expected discounted return is

$$J(T) = E\left[\sum_{n=1}^{\infty} e^{-\delta(X_1 + X_2 + \cdots + X_n)}(R_n - I)\right] \tag{4}$$

From Reed's observation, we employ the independence of the identically drawn X_i to write $J(T)$ as

$$J(T) = \frac{E[e^{-\delta X}(R - I)]}{[1 - E(e^{-\delta X})]} \tag{5}$$

and we can calculate[6]

$$E\left[e^{-\delta X}\right] = \frac{\left(\lambda + \delta\, e^{-(\lambda+\delta)T}\right)}{(\lambda + \delta)} . \tag{6}$$

To develop $E\left[e^{-\delta X}(R-I)\right]$, we have to acknowledge that the orchard yields a return of $r(t)$ at each point in time. Using (2), the first part can be derived as

$$
\begin{aligned}
E[e^{-\delta X}R] &= E\left[\int_0^X r(t)e^{-\delta t}dt\right] \\
&= \int_0^T \int_0^\tau r(t)e^{-\delta t}dt\,\lambda e^{-\lambda\tau}d\tau + e^{-\lambda T}\int_0^T r(t)e^{-\delta t}dt
\end{aligned}
\tag{7}
$$

and the second part as

$$
E\left[e^{-\delta X}I\right] = I\,E\left[e^{-\delta X}\right] = \frac{I\left[\lambda + \delta e^{-(\delta+\lambda)T}\right]}{(\lambda+\delta)}. \tag{8}
$$

Inserting (6), (7), and (8) into (5), the total site value can be calculated as

$$
\begin{aligned}
J(T) &= \frac{(\lambda+\delta)\,\lambda\int_0^T\int_0^\tau r(t)e^{-\delta t}dt\;e^{-\lambda\tau}d\tau}{\phi} \\
&+ \frac{(\lambda+\delta)e^{-\lambda T}\int_0^T r(t)e^{-\delta t}dt}{\phi} - \frac{I\left[\lambda+\delta e^{-(\lambda+\delta)T}\right]}{\phi}
\end{aligned}
\tag{9}
$$

where $\phi = \delta[1 - e^{-(\lambda+\delta)T}]$. As expressed in equation (9), the total return to the site is equal to the appropriately weighted expected revenue in the event of involuntary destruction plus the survival probability times the appropriately discounted expected revenue conditional on survival until planned replanting less the appropriately discounted cost of replanting in either event.

Impact of λ on Site Value

We can observe that the size of λ has two opposing effects on the total site value. This is easiest to ascertain from equation (5). One the one hand, the expected lifetime decreases with an increase in λ which lowers the denominator and increase the annualized cost of investment. Therefore, $E\left[e^{-\delta X}I\right]/\left\{1-E\left[e^{-\delta X}\right]\right\}$ as a whole increases. On the other hand, expected revenue is likely to decrease. In the case of an increase in λ, the expected return for the event $X = T$ decreases, but the probability-weighted return for the case $X < T$ can increase or decrease given *T*. If the overall expected return decreases, then both the numerator $E[e^{-\delta X} R]$ and the denominator $1 - E[e^{-\delta X}]$ decrease, so that the condition of decreasing expected lifetime return is not sufficient in order to sign $J_\lambda(\cdot)$. If the denominator $1 - E[e^{-\delta X}]$ decreases less than the expected lifetime return $E[e^{-\delta X} R]$ then $J(\cdot)$ would decrease as λ increases. However, this depends on the particular form of $r(t)$ and the size of δ and T^*. We derive the partial derivative of $J_\lambda(T)$ formally in appendix 4.

Replanting Decision

Differentiating $J(T)$ with respect to T and setting the derivative equal to zero gives implicitly the optimal lifetime of an orchard. Note that $d\phi/dT = \delta(\lambda+\delta)e^{-(\lambda+\delta)T}$, and so

$$\frac{dJ}{dT} = \frac{1}{\phi}\Big[(\lambda+\delta)\lambda \int_0^T r(t)\,e^{-\delta t}dt\,e^{-\lambda t} - \lambda(\lambda+\delta)e^{-\lambda T}\int_0^T r(t)\,e^{-\delta t}dt$$

$$+(\lambda+\delta)e^{-\lambda T} r(T)\,e^{-\delta T} + I\delta(\lambda+\delta)e^{-(\lambda+\delta)T} - \delta(\lambda+\delta)e^{-(\lambda+\delta)T}J(T)\Big] \qquad (10)$$

$$= \kappa\left[r(T) + \delta I - \delta J(T)\right]$$

where $\kappa = (\lambda+\delta)e^{-(\lambda+\delta)T}/\phi \neq 0$. Letting T^* denote the optimizing value, the first-order condition can be written as

$$r(T^*) = \delta J(T^*) - \delta I. \qquad (11)$$

The optimal orchard replanting time T^* depends on the discount rate δ, on the risk of orchard destruction by disease λ, on the shape of the price function $p(t)$, on the yield function $y(t)$, and on the cost function $c(t)$. The first-order condition states that the incremental return of keeping the orchard, $r(T^*)$, has to equal the rent from starting over $\delta[J(T^*) - I]$, so that the instantaneous return at T^*, $r(T^*)$, must be smaller than the average return $\delta J(T^*)$. Revenue at the replanting date must be exactly equal to the average return corrected for the cost of replanting.

The second-order condition requires $r_T(T^*) \leq 0 \Rightarrow p_T(T^*)y(T^*) + p(T^*)y_T(T^*) - c_T(T^*) \leq 0$ where we use the first-order condition to assert that $J_T(T^*) = 0$. If $r(t)$ increases, peaks and then falls substantially then a global maximum is likely. Henceforth we assume such a maximum.

Equilibrium

Equation (11) defines the optimal cycle length for one orchard. For the equilibrium analysis we assume that there exists a large acreage equally fit for apple production and that in the long run acres switch to or from apple production according to the opportunity cost of production. Each acre remains in apple production as long as the average return $\delta J(T^*)$ meets or exceeds the opportunity cost of land use and management, which is denoted by π_0. If $\delta J(T^*)$ decreases below π_0, then growers choose to leave apple production and employ the land in alternative activities such as cherry or pear production. If prices do not adjust, production is reduced to zero. Similarly, if $\delta J(T^*)$ increases, resources from other industries enter apple production and supply increases at an infinite rate. All orchards are equal and the supply for apples is assumed being perfectly elastic, an assumption that can be based on the notion of a long-run equilibrium as in Silberberg.

However, a supply shift according to changes in average returns or opportunity costs affects market prices, and an equilibrium analysis requires us to study the effect on prices and T^* simultaneously. To do so, we have to further characterize the dynamic structure of the industry. It is assumed that in a steady-state equilibrium an equal number of acres is planted each year. The price $p(t)$ is a function of orchard age and it is necessary to precisely define a shift in the price functions.

We develop the price function as $p(t) = a + s(t)$ and let $s(t)$ evolve according to orchard age. Explicitly, we set $s(0) = 0$ so that $p(0) = a$. Changes in $s(t)$ reflect decreases in quality occurring with orchard age (Funt et al.) and changes in the marketability of a variety. A change in the price schedule is then defined as a shift in the parameter $a > 0$.

The equilibrium price schedule is thus determined to equalize

$$\pi_0 = \delta J(T^*). \tag{12}$$

and equations (11) and (12) determine jointly the endogenous variables of the market equilibrium. The optimal replanting date T^* is chosen according to (11) and the parameter a adjusts to ensure condition (12).

To focus in on the risk aspect of the problem, we also restrict the cost function to be a step function such that $c(t) = c_N$ if $t \leq t_0$ and $c(t) = c_B$ if $t > t_0$, where t_0 is the time at which the orchard comes into full bearing. The cost of production are smaller in early years when orchards are in the nonbearing stage while they are larger when orchards are in full production. Our results carry over to more general cost functions; however, the model would become more cumbersome without leading to further insights into the problem.

We are now prepared to analyze the impacts of a change in λ, and to conduct a welfare analysis of such a change. The welfare analysis will use the change in price a and the accompanying changes in quantities produced and consumed in order to calculate changes in producer and consumer surpluses. But before we enter the estimation of welfare changes, we investigate the properties of the system with respect to changes in the production and market environment.

Equilibrium Analysis

We analyze the responses in market price a and replanting time T^* with respect to changes in the environment and technology using the equilibrium conditions (11) and (12). The analysis is simplified by the fact that $J_T(T)$ is zero in equilibrium, i.e., the Hessian is triangular. Therefore, (12) alone determines the change in a, so that we can always first sign an impact on a via totally differentiating (12), and then sign the impact on T^* using (11). To spare the reader from unnecessary technical detail, we refer the derivation of the partial derivatives of $J(T^*)$ to appendix 4A.

Investment

The analysis begins with the study of a change in the planting cost I. Totally differentiating (12) with respect to a, T^*, and I, we obtain $\delta J_T \, dT^* + \delta J_I \, dI + \delta J_a \, da = 0$. The first term equals zero by the first-order condition and we write $da / dI = -J_I(\cdot)/J_a(\cdot) \geq 0$ since $J_I(\cdot) \leq 0$ and $J_a(\cdot) \geq 0$. This confirms our intuition that an increase in investment cost needs to be compensated for by a price increase. From (11) we obtain dT^*/dI $= [\delta J_I - \delta + y(T^*)(J_I / J_a)]/r_T(T^*)$ which is positive, because the denominator is negative by the second-order condition. Thus, an increase in planting costs induces a deferral of the optimum replanting date in order to spread replanting costs over a larger volume of production.

Opportunity Cost

We continue with a shift in π_0, a change in the opportunity costs of apple production. Ignoring equilibrium impacts, an increase in π_0 encourages acres to be taken out of apple production. However, from (12) we conclude that $da/d\pi_0 = 1/\delta J_a(\cdot) \geq 0$, and an increase in the price schedule for apples restores equilibrium. In order to sign $dT/d\pi_0 \geq 0$, note that (11) is independent of π_0, so that the total differential results as

$$r_T(T^*)\, dT = \delta\, J_a(\cdot) \frac{da}{d\pi_0} d\pi_0 - r_a(T^*) \frac{da}{d\pi_0} d\pi_0$$

$$\Rightarrow \frac{dT^*}{d\pi_0} = \left[\frac{\delta J_a - y(T^*)}{r_T(T^*)} \right] \frac{da}{d\pi_0} \tag{13}$$

The expression $\delta J_a - y(T^*)$ measures the increase in annualized returns due to an upward shift in the price schedule and compares it to the increase in return due to deferring harvesting to a later point in time. If returns from delaying replanting exceed those that accrue in annualized returns, then T^* increases. This, however, depends on the revenue function over the entire time horizon and in general, it cannot be signed.

Cost Function

To analyze the impact of a change in cost, we have to first define a shift in the cost function. We parameterize the shift in $c(t)$ by θ such that $c(t) \rightarrow c(t) + \theta\, m(t)$ where $m(t) = m > 0$ if $t \in [t_1, t_2]$ and $m(t) = 0$ otherwise. Here $[t_1, t_2]$ can be any interval in t. Denoting $dJ(T)/d\theta$ by J_θ, it can be shown that $J_\theta = -\left[(\lambda+\delta)\lambda \int_0^T \int_0^\tau e^{-\delta t} m(t) dt\, e^{-\lambda\tau} d\tau\right]/\phi$ $-\left[(\lambda+\delta)\, e^{-\lambda T} \int_0^T e^{-\delta t} m(t) dt\right]/\phi < 0$. This holds true for a constant shift in $c(t)$ over any small interval, but the result can be generalized to hold for any upward shift in the cost function by decomposing the shift into a sum of small constant shifts. Since $J_\theta < 0$ for each of these small shifts, $J(T)$ decreases in any upward shift in the cost path.

Having signed J_θ, we can now turn to the effects of a change in $c(t)$ on equilibrium $p(t)$ and T^*. Note first that (12) implies that $J(T^*)$ is invariant. Therefore, for a change in cost, $da/d\theta = -J_\theta/J_a \geq 0$. From (11) we obtain $r_\theta d\theta + r_T dT^* + y(T^*)da - \delta J_\theta d\theta$ $- \delta J_a da = 0$. The latter two terms sum to zero by the total differential of (12), so that

$$\frac{dT^*}{d\theta} = \frac{-r_\theta(T^*) - y(T^*)da/d\theta}{r_T(T^*)} = \frac{-r_\theta(T^*) + y(T^*)J_\theta/J_a}{r_T(T^*)} \qquad (14)$$

the sign of which is ambiguous. It cannot be signed because J_θ depends on the particular form of the shift in $c(t)$. Even if we assume that $c(t)$ increases by a constant for all t, i.e. $m(t) = 1\ \forall t$, the numerator of (14) has the sign of $-\delta J_a + y(T^*)$. This cannot be signed as discussed in relation to equation (13) where we analyze the instance of a change in π_0. We conclude that an increase in costs triggers an increase in prices to prompt producers to remain in the apple growing business and that it has an ambiguous effect on the cycle length.

Output Productivity

Analogously to a change in cost we can derive the impact of a production function shift on $J(T)$ by denoting $y(t) \to y(t) + \psi k(t)$ so that $J_\psi \geq 0$. From (12) we obtain $da/d\psi$ $= -J_\psi/J_a < 0$. An increase in yield leads to a downward shift in the equilibrium price schedule. From (11), we can derive $dT^*/d\psi = \{[\delta J_a - y(T^*)]da/dy - p(T^*)\}/r_T(T^*)$ and the impact on T^* is indeterminate.

Mortality

As discussed in the previous section J_λ cannot be definitely signed but is quite likely to be negative. We differentiate (12) to obtain $da/d\lambda = -J_\lambda / J_a$ and equation (11) to yield $dT^*/d\lambda = \{[y(T^*) - \delta J_a] J_\lambda / J_a + \delta J_\lambda\} / r_T(T^*) = \{y(T^*) J_\lambda / J_a\} / r_T(T^*)$. Therefore, both effects depend on the sign of J_λ. If $J_\lambda < 0$ then an increase in risk lengthens the orchard cycle and causes an upward shift in the equilibrium price schedule. Our empirical study will show that this is true for the revenue functions that we study.

Table 1 summarizes all analytical comparative statics results. For all changes in the market and production environment but λ we can determine the change in at least one of the endogenous equilibrium variables. The indeterminacy of the second equilibrium variable arises because the response of the optimal cycle length with respect to a change in a cannot be determined. This response depends on the particular shape of the revenue function, and its entire time path determines the result. Further restrictions on the shape of the revenue function would be needed to derive unambiguous results for all shocks.[7]

Simulation Analysis of the Economic Impact of Antibiotics Use Removal

In order to assess the welfare impacts of a ban on antibiotics, we collect and analyze U.S. apple production data. We use yield data from Funt and from O'Rourke (1997) to estimate lifetime yield functions for apple orchards, employ prices from the Washington Growers Clearing House Association to derive a price schedule, and implement biological impact estimates from a U.S. Department of Agriculture - NAPIAP project that assesses the production impacts of pesticide bans in apple production (Rosenberger). Since apple trees yield fruit once a year, we conduct the simulation analysis using the discrete analogue of the analytical model.

Yield Function

Yield patterns over time vary depending on the production system. In traditional systems, a relatively low number of trees is planted per acre, but newer high-density systems increase yields per acre by planting a high number of trees. Funt reports yield data for plantings of four different densities; 66 trees/acre, 181 trees/acre, 605 trees/acre, and 792 trees/acre. His data concerns three varieties (York Imperial, Golden Delicious, and Red Delicious) over 36 years from planting to orchards of age 36 for each system. This gives us a matrix of 3×4 time series, each with a length of 36 years.

Apple yields can fluctuate considerably between years depending on weather and pest conditions, and we smooth the data by using a five-year moving average. Zeros are implemented in the first two moving average, and so 34 years of yield data remain.[8] A preliminary study of the data revealed that yield patterns over an orchard's lifetime are quite different depending on the planting density, but are rather homogeneous across varieties for systems of the same tree density. This impression was confirmed in discussions with experts of the apple industry. For this reason, four different yield functions for the four different tree densities were estimated using the data for all three varieties in each of them. The yield function was specified as

$$\ln y_t = a_0 + a_1 t + a_2 \ln t + a_3 \frac{1}{t} + a_4 \frac{1}{t^2} \qquad (15)$$

where $\ln y_t$ is the natural logarithm of yield at orchard age t, and $a_0, \ldots, a_4$ are the parameters to be estimated. The function was estimated using a fixed-effect model to account for differences in the slope of $\ln y_t$ which result in multiplicative differences in y_t.[9] The parameter estimates are given in table 2 together with goodness of fit measures, where yield 1 reports the estimates for 66 trees/acre, yield 2 the estimates for 181 trees/acre etc. The F-test examines the hypothesis of equal intercepts for the different varieties and including fixed effects is therefore appropriate. Figure 1a plots the four different yield functions that were estimated using Funt's data.[10]

In addition to these yield data for different orchard designs by Funt, we use data by O'Rourke (1997) who estimates the yield for an average orchard in the state of Washington.[11] This yield function (yield 5) gives data for 41 years of orchard age and is plotted in figure 1b.

For the welfare analysis we normalize the yield functions so that the average yield will equal the U.S. average yield of 23,500 lb./acre under the assumption that an equal number of acres of each maturity are in production. This normalization will depend on the estimated optimal cycle length that results from the optimization of $J(T)$ and will therefore depend on the cost, investment, and price data. We plot the yield functions in figures 1a and 1b in a way such that each function is normalized to yield the same maxima.

Price Function

Little data is available to estimate the price function. Discussions with many industry specialists indicated to us that price decreases for the orchard crop are a major reason for replanting an orchard. For a particular variety prices may decrease because of supply increases and changes in the demand. In addition to price changes by variety, the value of crop from a particular genetic material may change according to details such as coloring or storage quality of the apples. The data to estimate these effects is sparse and ignores many quality and demand effects.

We obtain price data by variety from the Washington Growers Clearing House Bulletin to estimate a price function by variety. For the newer varieties Gala, Fuji, Braeburn, and Jonagold we have data for the production years 1992/93 through 1997/98 and use it to estimate price as a function of time using an exponential function with positive intercept as a lower limit for price. This lower limit is chosen to be the average price received for apples in the processed sector (7.54 ¢/lb.) and the restriction on the intercept is imposed in the estimation procedure. The function is estimated as

$$p_t = 0.0754 + (0.737 + 0.221D_1 - 0.183D_2 - 0.102D_3)\ \exp(-0.134t) \qquad (16)$$
$$\qquad (9.223)\ (2.535)\quad (-2.112)\quad (-1.189)\qquad (-5.230)$$

where D_1, D_2, and D_3 represent dummy variables to distinguish the multiplicative term for the different varieties. The numbers in parenthesis report t-values and the R^2 of regression equals 0.72. The test statistic on the restriction is $F(1,18)=11.6$ and is F-distributed.

For the estimation of welfare impacts, the price function is calibrated to yield the U.S. average price of 15.31 ¢/lb. by adjusting the multiplicative term to the exponential function. We refer to this price function as price 1.

An alternative price function is specified to capture price developments for orchards whose crop does not loose value because of demand and supply effects for the particular variety but because of changes in the quality of apples. The function assumes an s-shaped form and is formulated as

$$p_t = [1 + \exp((t - 25)/5)]^{-1}$$

It is denoted by price 2 and is similarly to price 1 calibrated to yield an average price of 15.31 ¢/lb. and to have a lower bound of 7.54 ¢/lb. Both price functions are plotted in figure 2.

Cost Function

Two specification for the cost function were chosen using evidence from enterprise budgets for apple orchards (Bechtel et al.; Carkner, Havens, and MacConnell; Dickrell, Hinman, and Tvergyak; Funt et al.; Hinman et al. (1993a, 1993b); Hinman, Williams, and Faubion; Marshall et al.; Parker et al.; Seavert and Burkhart). They are specified as a discrete step function with low cost (c_1 = $1,700/acre; $1,200/acre) in early years for $t \leq 5$ and higher cost (c_2 = $2,500; $2,000) in later years for $t \geq 6$. The set (c_1; c_2)=($1,700; $2,500) will henceforth be referred to as cost 1, and the set (c_1; c_2)=($1,200; $2,000) as cost 2. Evidence from these sources also motivated our choice for I to lie between $6,000/acre and $8,000/acre.

Replanting Time and Price Adjustments

We analyze the impacts of changes in the production environment on the long-run equilibrium of the apple industry. Some general production statistics for the U.S. apple industry are given in table 3. For the simulation analysis, the base level of λ is set at 0.01 based on tree survival probabilities in O'Rourke (1997) and the discount rate δ is set approximately at the real rate of return on long-term securities at 0.04. Based on expert surveys, Rosenberger estimates that a loss of antibiotics for fire blight management will lead to a decrease in yield by 8% and an acreage reduction by 8.7% in the next five years. Under the assumption of a Poisson process, the acreage loss is equivalent to a value of λ =0.027. Cost of production increases are almost negligible at $2.6/acre.

We employ these data to estimate the impact of an antibiotics ban using the different yield, price, cost, and investment function specifications. For this estimation, $J(T)$ is calculated in discrete form using the annual return data for each of the functional specifications. We calculate the optimal replanting time under our baseline assumptions (T_0) together with the base return (π_0). Increasing λ to 0.027 and simultaneously decreasing yield by 8%, we vary a and calculate the new $T^* = T_1$ such that $\delta J(T_1, a_1) = \delta J(T_0, a_0)$. Estimates are given in tables 4a and 4b for all combinations of the functional specification, where table 4a shows results for price 1 and table 4b for price 2.

Because experts are often thought to include a risk premium in their impact estimates we repeat the simulation for reduced estimates for the change in yield and λ, setting the reduction in yield to 4% and $\lambda_1 = 0.0185$. The results are recalculated for price 1 and given in table 5.

We can observe that changing from the low-density planting (yield 1 and 2) to high-density plantings (yield 3 and 4), increases profits, which coincides with the observation of a shift towards plantings of high-density orchard in the United States. High-density orchards have a lower optimal life length, as can be observed when studying different apple production systems (O'Rourke, 1993, p. 35). Using the original expert estimates the change in price after losing antibiotics varies between 2.1 and 3.2 ¢/lb. (14-21%) at the farm level and the increase in replanting age adjusts by between 2-8 years (table 4a). For price 2, the optimal replanting is delayed as prices decrease more slowly. Using the reduced impact estimates, adjustments in prices and optimal replanting time are reduced accordingly (table 5).

To gain a better understanding of how different values for λ and changes in average yield would impact the equilibrium conditions, we study one revenue and investment function specification in more detail. For this exercise we choose price 1, Yield 3, I = \$6000, and cost 2. We vary λ from 0.01 to 0.03 and reduce average yields by values between 0 and 3000 lb./acre/year. The resulting responses for T_1 are shown figure 3, and for Δa in figure 4. It can be observed that T_1 and Δa increase as impacts become stronger. This is consistent with J_λ being negative and so as the risk of mortality increases, growers defer replanting as the probability of recovering the investment of replanting is lower.

The figures show an approximately linear response of T_1 and Δa to changes in yield and λ. This is confirmed when comparing tables 4a and 5, where we observe that the reduction of production impacts by 50% imply that adjustments in T^* and Δa are approximately cut in half.

We carry our simulation analysis further and obtain estimates of welfare impacts resulting from a ban on antibiotics. Implementing a partial-equilibrium model, we estimate changes in apple supply and demand and use the resulting changes to calculate changes in consumer and producer surplus. The partial-equilibrium model for the U.S apple market including net imports is described by

$$Q^D(P) = Q^D \tag{16.1}$$

$$M(P, Q^P) = M \tag{16.2}$$

$$Q^P + M = Q^D \tag{16.3}$$

Equation (16.1) describes the demand function (Q^D) as a function of price (P), (16.2) depicts the net import equation (M) as a function of price (P) and home production (Q^P), and lastly equation (16.3) poses the market clearing condition. Q^P is modeled as being invariant to prices because we assume a perfectly elastic supply function for our equilibrium analysis.

Given the change in price (Δa) as calculated from the production system of the individual orchard [equations (11) and (12)], we can derive the changes in quantities demanded and supplied by totally differentiating (16) and so obtain

$$\left(\frac{\partial Q^D}{\partial P}\frac{P}{Q^D}\right)\frac{Q^D}{P}\Delta a = \Delta Q^D \tag{17.1}$$

$$\left(\frac{\partial M}{\partial P}\frac{P}{M}\right)\frac{M}{P}\Delta a + \left(\frac{\partial M}{\partial Q^P}\frac{Q^P}{M}\right)\frac{M}{Q^P}\Delta Q^P = \Delta M \tag{17.2}$$

$$\Delta Q^P + \Delta M = \Delta Q^D \tag{17.3}$$

System (17) is linear in the changes ΔQ^D, ΔM, and ΔQ^P, and thus can easily be solved given the appropriate elasticity estimates and data on current quantities and prices.

Elasticity estimates have been obtained in a study that was conducted to estimate the impacts of pesticide losses in apple production (appendix 2A). The demand elasticity is set to –0.55, the elasticity of imports with respect to prices is estimated as –0.76, and the elasticity of imports with respect to home production is –3.3. Given production and yield changes, we can calculate the change in acreage (ΔAcre) and the change in producer surplus as ΔAcre × π_0. Consumer surplus changes are calculated as $dCS = -(Q + \Delta Q/2)\Delta a$.

Tables 4a, 4b, and 5 show the estimated changes in quantity demanded and supplied together with the estimated welfare changes in the lower part of each cell. The results vary given the host of revenue functions that enter our analysis and depend in particular on the size of price increase needed to compensate growers for profit losses caused by changes in the risk environment. In general for price 1, consumption decreases by about 940 mill. lb.

(440 mill. lb.) given (reduced) expert estimates, production decreases by 1.6 bill. lb. (0.7 bill. lb.) and U.S. apple acreage decreases by between 45,700 and 69,700 (22,300 and 37,200) acres or by between 10% and 15% (5% and 6%). Welfare losses are in the vicinity of $320 mill. ($155 mill.). For price 2, the impacts are slightly larger.

The variation in the results indicates that the estimates of welfare changes are ball part figures, and also, they appear relatively high. We compare the results to simulation results obtained in a model of marginal supply function shifts in response to the same yield and cost of production changes (chapter 2) and estimate a welfare losses of -$62.2 mill. using long-run (year 5) elasticities. This model here yields a loss of $175 mill. when we include only yield and cost changes and ignore the changes in survival probability. So this model yields higher welfare losses, a result that is in part caused by the fact that the length of run is much higher in this analysis and adjustments of the industry will in general be stronger.

To interpret the results of this simulation, we have to remind ourselves of the assumptions that enter the derivation of these estimates. We treat all growers alike and shift the perfectly elastic supply curve in a parallel way. Price increases would be smaller if we used an increasing supply curve, and in addition some grower groups might be less affected by a ban on antibiotics. We ignore any changes in yield in response to an increase in prices and in particular our model does not include technological change. If antibiotics are banned, it is most likely that the value of fire blight resistance in a variety would increase and growers would change the current trend of planting varieties of higher susceptibility. This would in turn reduce the change in λ. Our overall estimates should be interpreted as an upper bound on welfare impacts.

Conclusion

We have developed an equilibrium model of the decision to replant fruit orchards incorporating the risk that an orchard could be destroyed by disease or other adverse events. The model facilitates thinking about long-term issues of pest control for perennial crops and the decision to replant and it could be used to analyze the impact of changes in the survival probabilities of any kind of long-term investment project. Our result is more flexible than Reed's who analyzes the decision to cut and replant a forest incorporating the risk of forest fire, because in our case revenue is not restricted to accrue at a single point in time. We employ the model to simulate losses resulting from a ban on antibiotics in U.S. apple production and we estimate welfare losses of about $320 mill., where the result should be interpreted as an upper bound given the limitations of the simulation analysis.

About 50% of all antibiotics used in the U.S. are used in agriculture, the vast majority as growth enhancers in animal production. Still, 30% of U.S. apple acreage are treated with antibiotics (U.S. Department of Agriculture) and the most common application of the broad-spectrum antibiotic streptomycin occurs is the treatment of fire blight in apple and pear production. Given the recent critical attention to antibiotics use in agriculture, an analysis of the welfare impact following a antibiotic removal in fruit production is urgently needed.

With this paper we attempt to initiate a discussion of the importance of antibiotics in fruit production. A complete analysis of the economic impact would in addition require a precise analysis of the risk of antibiotics use on human exposure to resistant pathogens. Experts agree that antibiotics use in food production encourages the development of antibiotic-resistant human pathogens. But the importance of this link is currently hotly debated. If the link between resistance development in plant and human pathogens is strong, then the impact of increasing the prevalence of antibiotic resistant bacteria on human welfare is likely to have a large effect on human welfare. The cost of increased antibiotic resistance is not negligible. Sawert estimates that treatment cost alone for would increase from $20,000 to $180,000 for tuberculosis patients with resistant *Mycobacterium tuberculosis.*

A good place to begin the economic analysis of the human health benefits could be Harper and Zilberman, who incorporate worker health risk into the analysis of pesticide regulation. A line of research by Foreman, by Sawert, and by Wallace and Wallace that was stimulated by the newly observed resurgence of tuberculosis in some subpopulations would also be of interest given the epidemic character of diseases that are affected by antibiotic resistance. Furthermore, Philipson shows how to acknowledge the cost of disease avoidance effort in health economic studies, and it is likely that these costs would increase if the probability of effective treatment declines.

On the producer side of the economic assessments, more data on yield, price and cost trajectories are needed for a more precise welfare estimate. In particular, it would be desirable to be able to distinguish between different grower groups in the analysis. Further research could focus on technological and institutional adjustments, such as insurance markets, that could lessen the welfare impacts due to restrictions on antibiotic use.

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Notes

[1] Graduate assistant at the Department of Economics, Iowa State University.

[2] I would like to thank Dave Rosenberger for discussing with me the nature of blight management and providing the impact data, and to thank Dick Funt, Desmond O'Rourke, and the Washington Growers Clearing House Association for providing me additional yield and price time-series data. Further thanks I owe to David Hennessy, Bruce Babcock, Joe Herriges, Alicia Carriquiry and Catherine Kling for helpful comments on earlier drafts of the paper.

[3] *Enterococcus faecalis* is a streptococcus that invades the intestinal tract and can be pathogenic in patients with weak immune systems. *Mycobacterium tuberculosis* causes

tuberculosis, and *Pseudomonas aeruginosa* is a bacterium that lives in soil or water, but it can also be pathogenic and cause urinary-tract infections.

4 In this specification, marginal harvest costs can be accommodated by adjusting the price function.

5 This assumption is not very restrictive for our problem. Disease outbreaks are often related spatially for a given year because the bacteria spreads epidemically through a region, but little dependence would be expected between replantings across time.

6 Employing (3), expression (6) follows from

$$E\left[e^{-\delta X}\right]=\int_0^T \lambda e^{-\lambda t}\, e^{-\delta t}dt+e^{-\lambda T}e^{-\delta T}=\frac{\lambda\left(1-e^{-(\lambda+\delta)T}\right)}{\lambda+\delta}+e^{-(\lambda+\delta)T}=\frac{\lambda+\delta e^{-(\lambda+\delta)T}}{\lambda+\delta}$$

7 Using results on qualitative comparative statics by Quirk, it can be shown that the system is fully sign-solvable only for *I*. For all the other comparative statics but with respect to λ, the system is partially sign-solvable.

8 Using zeros in the moving average for the first two years seemed to be the best way to proceed as in most cases yield is zero in the first three years in any case.

9 A random-effect model was also implemented for the estimation of the yield and price function. However, the Hausman test rejected the hypothesis that the random effects are uncorrelated with the explanatory variables for some functions. Therefore we preferred the fixed-effects specification.

10 The yield data was collected from growers in Pennsylvania in the early 1970s. It would have been preferable to cover a wider geographical range and a higher number of varieties. However, to our knowledge there do not exist other data covering orchards over so many years. Part of the problem is that we need to estimate the yield trajectory beyond

the typical replanting date. We compare our results with European data of Goedebure (1980, 1986) and discussed the issue with members of the apple industry. It appears that yield trajectories depend mostly on the orchard system planted so that for the four given systems our estimates appropriately describe the orchard productivity over time.

[11] O'Rourke (1997) estimates the yield curve by employing available data from fruit censi in the state of Washington and additional evidence from the industry.

Table 1. Summary of Comparative Statics Results

	$d\pi_0$	$d\theta^a$	$d\psi^b$	$d\lambda$	dI
da	+	+	-	-/+	+
dT^*	-/+	-/+	-/+	-/+	+

[a] dθ parameterizes a shift in the cost function.
[b] dψ parameterizes a shift in the yield function.

Table 2. Parameter Values for Yield and Price Function[a, b]

	Yield 1	Yield 2	Yield 3	Yield 4
a_1	6.857	1.114	-0.763	1.266
	(10.607)	(5.751)	(-1.666)	(5.528)
a_2	-0.259	-0.048	-0.002	-0.066
	(-12.396)	(-5.447)	(-0.094)	(-7.355)
a_3	28.481	-3.447	-15.813	-2.391
	(5.651)	(-4.785)	(-6.257)	(-1.893)
a_4	-26.8455	[c]	8.887	2.067
	(-5.510)		(6.204)	(2.886)
F-test[d]	159.3	134.9	19.1	58.7
R^2	98.6	97.5	95.4	97.9

[a] The estimate for the intercept a_0 is not listed as the fixed effect model estimates a different intercept for each time series.
[b] The values in parentheses report t-values.
[c] This term was excluded to improve the fit of the estimation according to the adjusted R^2.
[d] The degrees of freedom for the F-tests are (2,93), (2,93), (2,95), and (2,95) for yield 1-4, respectively.

Table 3: U.S. Apple Production Data, 1994-96

	Unit	Average
Acreage	thsnd. acres	449.6
Yield	lb./acre	23,500.0
Production	mill. lb.	10,654.1
Net Imports	mill. lb.	1,763.1
Average Price	¢/lb.	15.31
Price for Processed Apples	¢/lb.	7.54

Table 4a. Ban on Antibiotic Use: Original Impacts employing Price 1[a]

				Yield 1	Yield 2	Yield 3	Yield 4	Yield 5
Cost 1	I=6000	π_0	$	694.2	918.8	915.1	964.0	871.8
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	31.0	33.0	25.0	26.0	33.0
		Δa	¢/lb.	3.0	2.3	2.2	2.1	2.6
		ΔQ^D	mill. lb.	-1,129.3	-871.3	-804.0	-785.3	-961.0
		ΔQ^P	mill. lb.	-1,900.0	-1,465.9	-1,352.6	-1,321.2	-1,616.8
		ΔAcre	thsnd. a	-57.8	-66.6	-45.9	-46.3	-60.3
		ΔCS	mill. $	-310.3	-242.4	-224.4	-219.4	-266.2
		ΔPS	mill. $	-40.1	-61.2	-42.0	-44.7	-52.6
	I=8000	π_0	$	671.1	888.1	870.9	922.3	846.6
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	31.0	35.0	26.0	27.0	34.0
		Δa	¢/lb.	3.2	2.5	2.3	2.2	2.7
		ΔQ^D	mill. lb.	-1,200.4	-927.4	-848.9	-833.9	-1,024.6
		ΔQ^P	mill. lb.	-2,019.5	-1,560.2	-1,428.1	-1,402.9	-1,723.8
		ΔAcre	thsnd. a	-58.1	-69.7	-46.3	-46.5	-61.1
		ΔCS	mill. $	-328.7	-257.3	-236.4	-232.4	-283.0
		ΔPS	mill. $	-39.0	-61.9	-40.3	-42.9	-51.8
Cost 2	I=6000	π_0	$	1,186.3	1,410.9	1,407.3	1,456.1	1,363.9
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	31.0	33.0	25.0	25.0	33.0
		Δa	¢/lb.	3.0	2.3	2.1	2.1	2.6
		ΔQ^D	mill. lb.	-1,121.8	-867.5	-800.2	-781.5	-957.3
		ΔQ^P	mill. lb.	-1,887.4	-1,459.6	-1,346.3	-1,314.9	-1,610.6
		ΔAcre	thsnd. a	-57.2	-66.4	-45.7	-40.8	-60.0
		ΔCS	mill. $	-308.4	-241.4	-223.4	-218.4	-265.2
		ΔPS	mill. $	-67.9	-93.7	-64.3	-59.4	-81.9
	I=8000	π_0	$	1,163.2	1,380.3	1,363.1	1,414.4	1,338.7
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	31.0	35.0	26.0	27.0	34.0
		Δa	¢/lb.	3.2	2.5	2.3	2.2	2.7
		ΔQ^D	mill. lb.	-1,196.6	-923.6	-845.1	-830.2	-1,020.9
		ΔQ^P	mill. lb.	-2,013.2	-1,553.9	-1,421.8	-1,396.7	-1,717.5
		ΔAcre	thsnd. a	-57.8	-69.4	-46.0	-46.2	-60.9
		ΔCS	mill. $	-327.7	-256.3	-235.4	-231.4	-282.0
		ΔPS	mill. $	-67.2	-95.8	-62.7	-65.3	-81.5

[a] T_0, T_1, and Δa are calculated according to equations (11) and (12). ΔQ^D and ΔQ^P follow from the partial equilibrium model (17).

Table 4b. Ban on Antibiotic Use: Original Impacts employing Price 2[a]

				Yield 1	Yield 2	Yield 3	Yield 4	Yield 5
Cost 1	I=6000	π_0	$	473.3	693.4	762.6	758.7	617.8
		T_0	yrs.	31.0	32.0	28.0	29.0	33.0
		T_1	yrs.	33.0	37.0	31.0	31.0	36.0
		Δa	¢/lb.	3.4	2.9	2.5	2.6	3.1
		ΔQ^D	mill. lb.	-1,275.1	-1,071.4	-938.6	-957.3	-1,166.7
		ΔQ^P	mill. lb.	-2,145.3	-1,802.4	-1,579.1	-1,610.6	-1,962.9
		ΔAcre	thsnd. a	-59.3	-53.7	-39.2	-37.6	-56.1
		ΔCS	mill. $	-347.9	-299.9	-260.3	-265.2	-320.0
		ΔPS	mill. $	-28.1	-37.2	-29.9	-28.5	-34.7
	I=8000	π_0	$	426.4	649.4	731.0	708.0	574.0
		T_0	yrs.	31.0	33.0	29.0	29.0	33.0
		T_1	yrs.	33.0	39.0	32.0	32.0	37.0
		Δa	¢/lb.	3.6	3.0	2.7	2.7	3.3
		ΔQ^D	mill. lb.	-1,331.2	-1,136.8	-994.7	-1,005.9	-1,222.8
		ΔQ^P	mill. lb.	-2,239.7	-1,912.5	-1,673.5	-1,692.3	-2,057.2
		ΔAcre	thsnd. a	-63.6	-62.3	-42.5	-42.9	-61.7
		ΔCS	mill. $	-362.2	-312.3	-275.1	-278.1	-334.5
		ΔPS	mill. $	-27.1	-40.5	-31.1	-30.4	-35.4
Cost 2	I=6000	π_0	$	965.4	1,185.5	1,254.7	1,250.8	1,109.8
		T_0	yrs.	31.0	32.0	28.0	29.0	33.0
		T_1	yrs.	33.0	37.0	31.0	31.0	36.0
		Δa	¢/lb.	3.4	2.9	2.5	2.6	3.1
		ΔQ^D	mill. lb.	-1,267.7	-1,067.7	-934.9	-953.6	-1,163.0
		ΔQ^P	mill. lb.	-2,132.7	-1,796.3	-1,572.8	-1,604.3	-1,956.6
		ΔAcre	thsnd. a	-58.7	-53.4	-39.0	-37.3	-55.9
		ΔCS	mill. $	-346.0	-298.9	-259.3	-264.3	-319.0
		ΔPS	mill. $	-56.7	-63.3	-48.9	-46.7	-62.0
	I=8000	π_0	$	918.5	1,141.4	1,223.1	1,200.1	1,066.1
		T_0	yrs.	31.0	33.0	29.0	29.0	33.0
		T_1	yrs.	33.0	39.0	32.0	32.0	37.0
		Δa	¢/lb.	3.6	3.0	2.7	2.7	3.3
		ΔQ^D	mill. lb.	-1,327.5	-1,136.8	-990.9	-1,002.2	-1,219.1
		ΔQ^P	mill. lb.	-2,233.4	-1,912.5	-1,667.2	-1,686.0	-2,050.9
		ΔAcre	thsnd. a	-63.3	-62.3	-42.2	-42.7	-61.5
		ΔCS	mill. $	-361.3	-312.3	-274.1	-277.1	-333.5
		ΔPS	mill. $	-58.2	-71.1	-51.6	-51.2	-65.5

[a] T_0, T_1, and Δa are calculated according to equations (11) and (12). ΔQ^D and ΔQ^P follow from the partial equilibrium model (17).

Table 5. Ban on Antibiotic Use: Reduced Impacts employing Price 1[a]

				Yield 1	Yield 2	Yield 3	Yield 4	Yield 5
Cost 1		π_0	$	694.2	918.8	915.1	964.0	871.8
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	30.0	29.0	23.0	24.0	31.0
		Δa	¢/lb.	1.4	1.1	1.0	1.0	1.2
	I=6000	ΔQ^D	mill. lb.	-527.3	-415.1	-385.2	-373.9	-452.5
		ΔQ^P	mill. lb.	-887.1	-698.3	-648.0	-629.1	-761.2
		ΔAcre	thsnd. a	-28.2	-32.5	-22.7	-23.0	-32.7
		ΔCS	mill. $	-149.1	-118.0	-109.7	-106.5	-128.4
		ΔPS	mill. $	-19.6	-29.9	-20.8	-22.2	-28.5
		π_0	$	671.1	888.1	870.9	922.3	846.6
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	30.0	31.0	24.0	25.0	31.0
		Δa	¢/lb.	1.5	1.2	1.1	1.1	1.3
	I=8000	ΔQ^D	mill. lb.	-557.2	-437.5	-407.6	-396.4	-478.6
		ΔQ^P	mill. lb.	-937.4	-736.1	-685.7	-666.9	-805.3
		ΔAcre	thsnd. a	-24.9	-37.2	-22.5	-22.7	-27.3
		ΔCS	mill. $	-157.4	-124.3	-115.9	-112.8	-135.7
		ΔPS	mill. $	-16.7	-33.1	-19.6	-20.9	-23.1
Cost 2		π_0	$	1,186.3	1,410.9	1,407.3	1,456.1	1,363.9
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	30.0	29.0	23.0	24.0	31.0
		Δa	¢/lb.	1.4	1.1	1.0	1.0	1.2
	I=6000	ΔQ^D	mill. lb.	-523.5	-411.3	-381.4	-373.9	-448.7
		ΔQ^P	mill. lb.	-880.8	-692.0	-641.7	-629.1	-754.9
		ΔAcre	thsnd. a	-27.9	-32.3	-22.4	-23.0	-32.5
		ΔCS	mill. $	-148.1	-117.0	-108.6	-106.5	-127.4
		ΔPS	mill. $	-33.2	-45.5	-31.5	-33.6	-44.3
		π_0	$	1,163.2	1,380.3	1,363.1	1,414.4	1,338.7
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	30.0	31.0	24.0	25.0	31.0
		Δa	¢/lb.	1.5	1.2	1.1	1.1	1.3
	I=8000	ΔQ^D	mill. lb.	-553.4	-437.5	-403.9	-396.4	-478.6
		ΔQ^P	mill. lb.	-931.1	-736.1	-679.5	-666.9	-805.3
		ΔAcre	thsnd. a	-24.6	-37.2	-22.3	-22.7	-27.3
		ΔCS	mill. $	-156.3	-124.3	-114.9	-112.8	-135.7
		ΔPS	mill. $	-28.6	-51.4	-30.4	-32.1	-36.6

[a] T_0, T_1, and Δa are calculated according to equations (11) and (12). ΔQ^D and ΔQ^P follow from the partial equilibrium model (17).

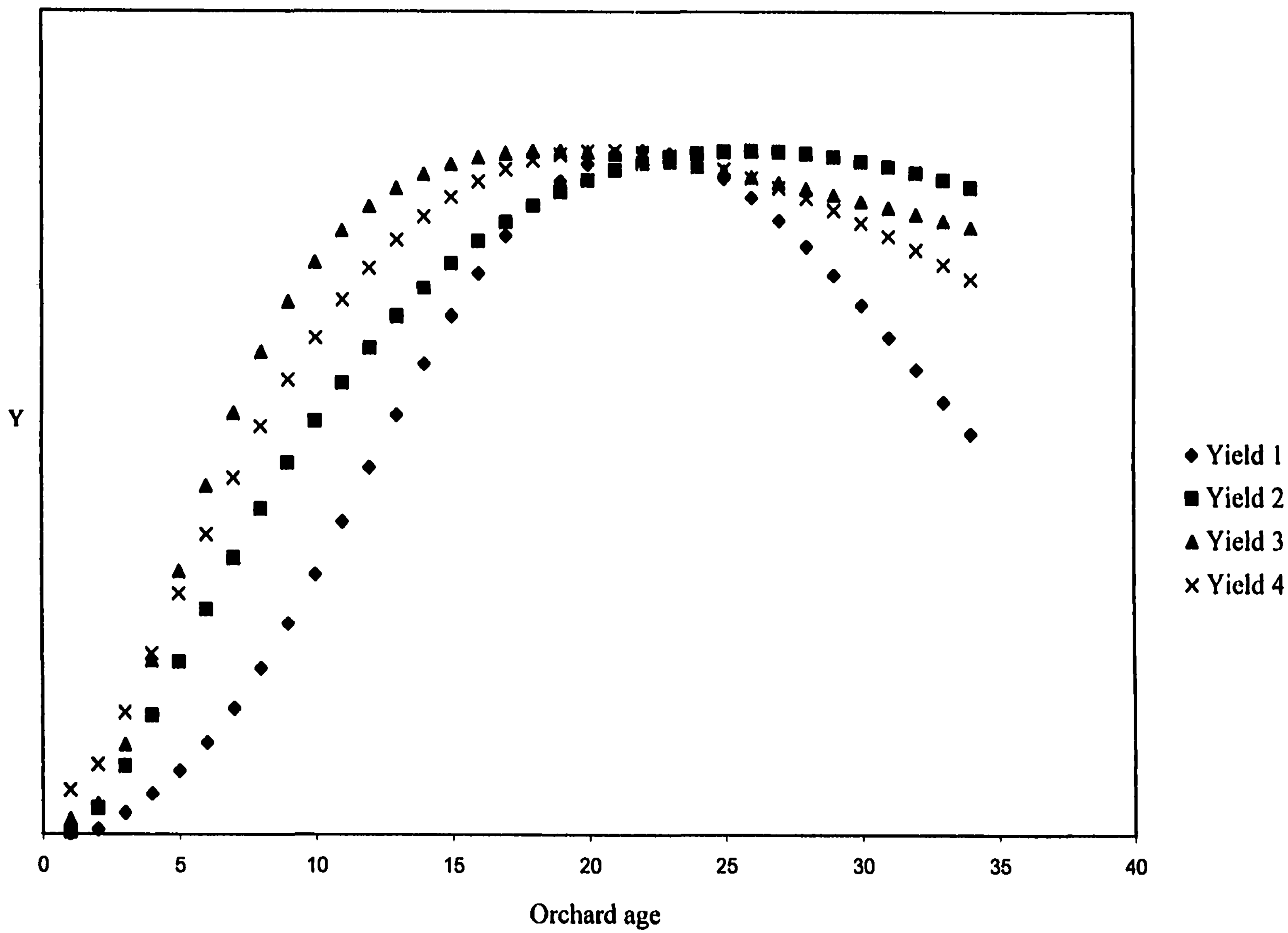

Figure 1a. Yield Functions

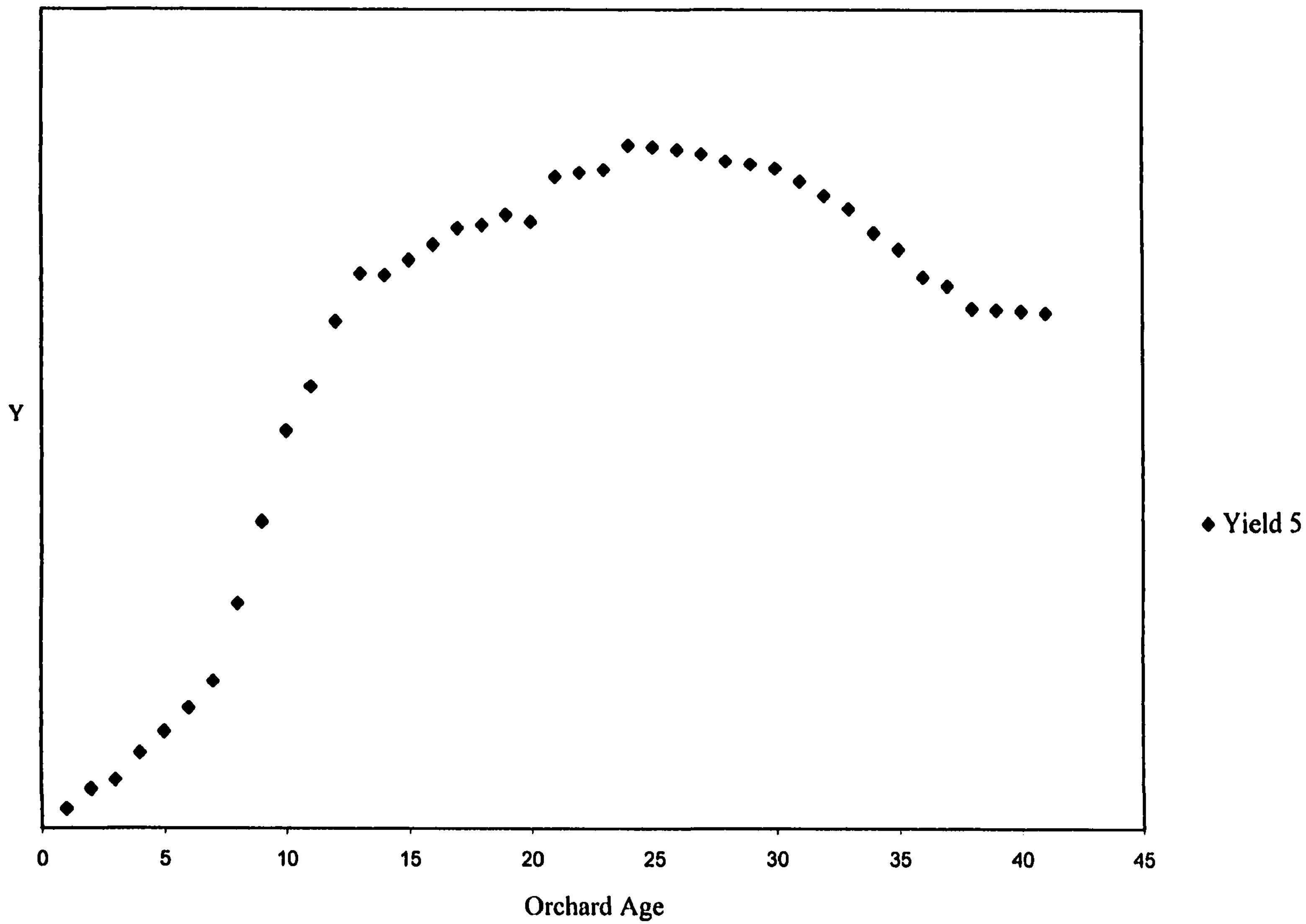

Figure 1b. Yield Functions (continued)

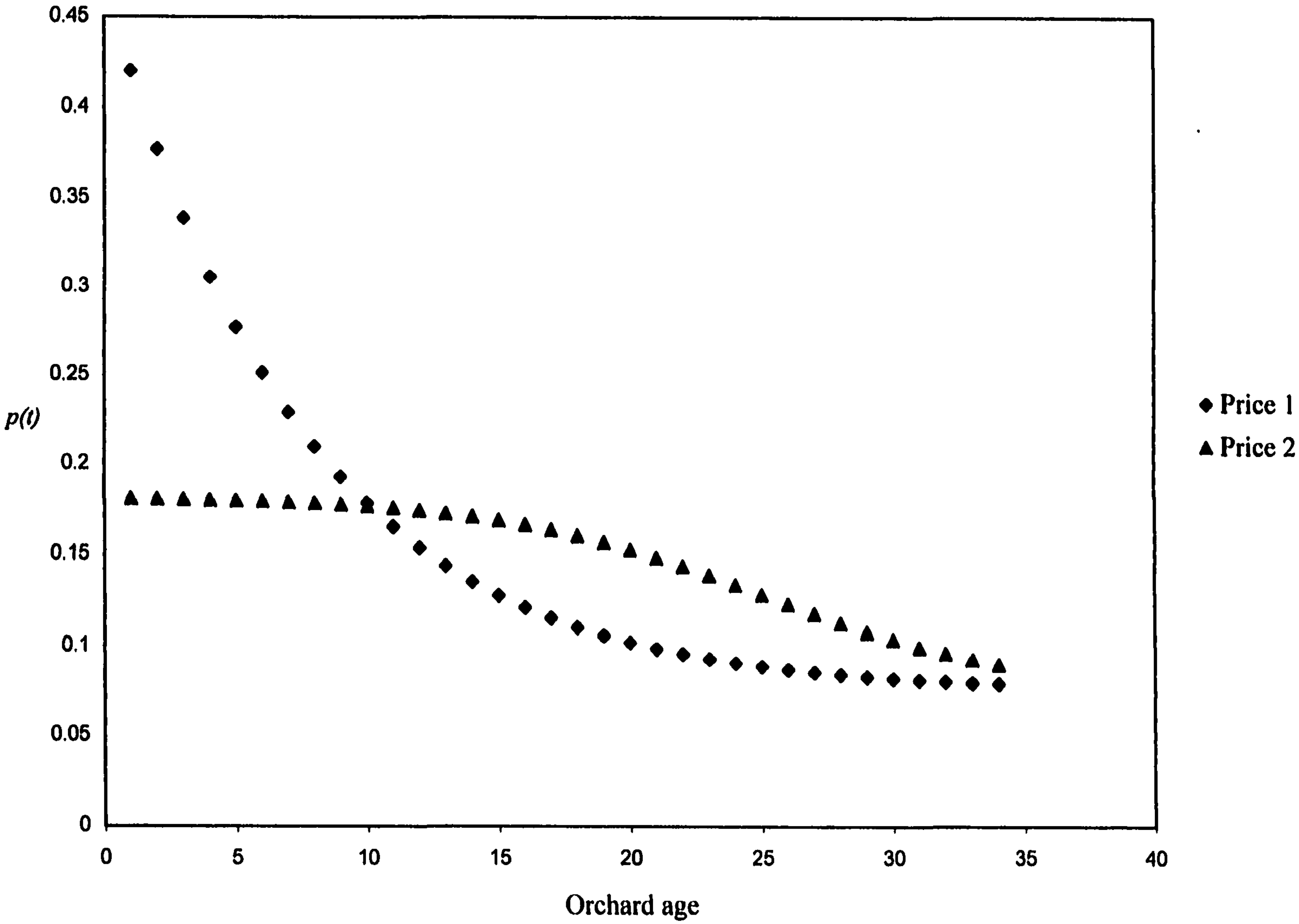

Figure 2. Price Functions

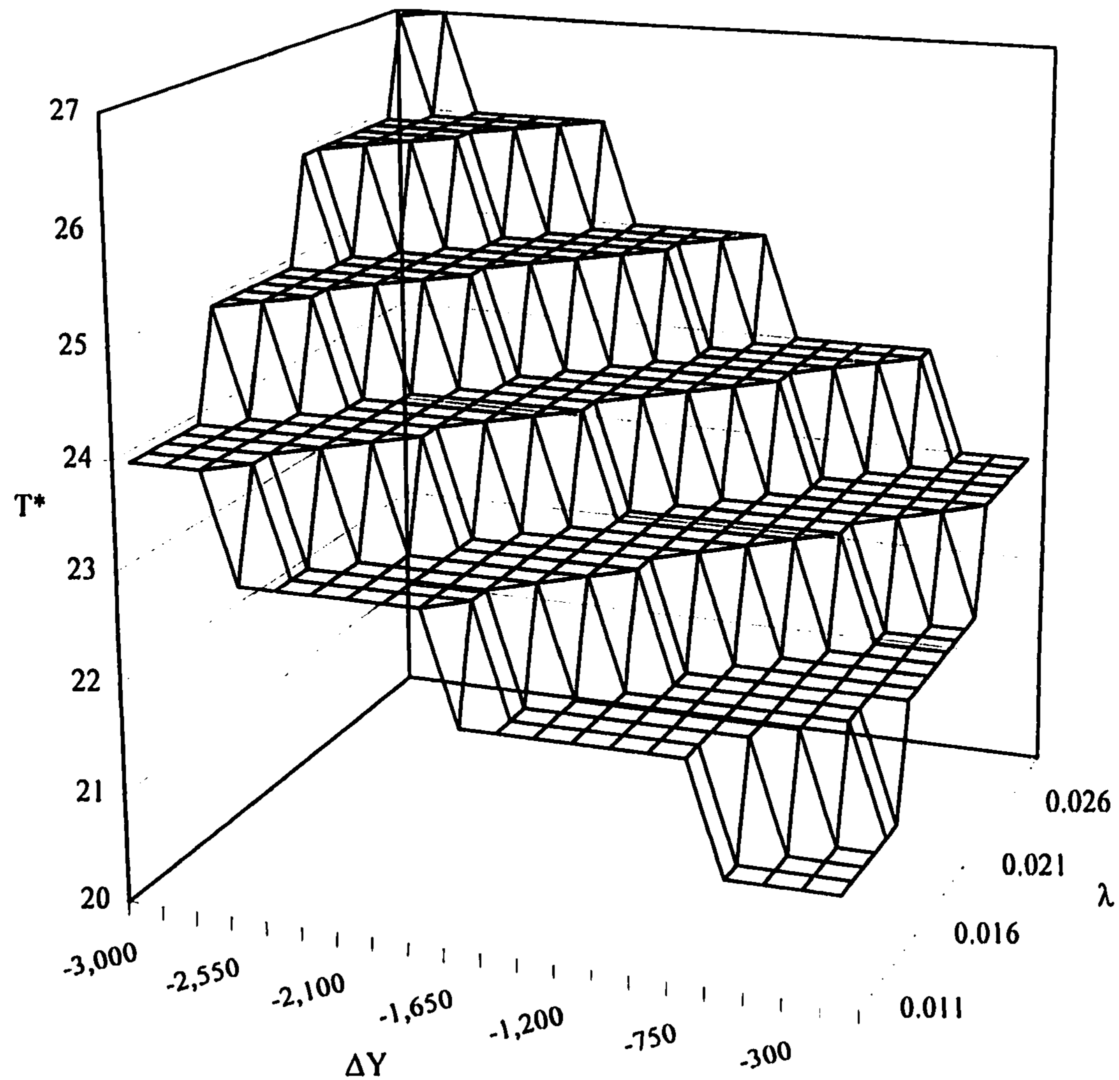

Figure 3: Adjustment in T*

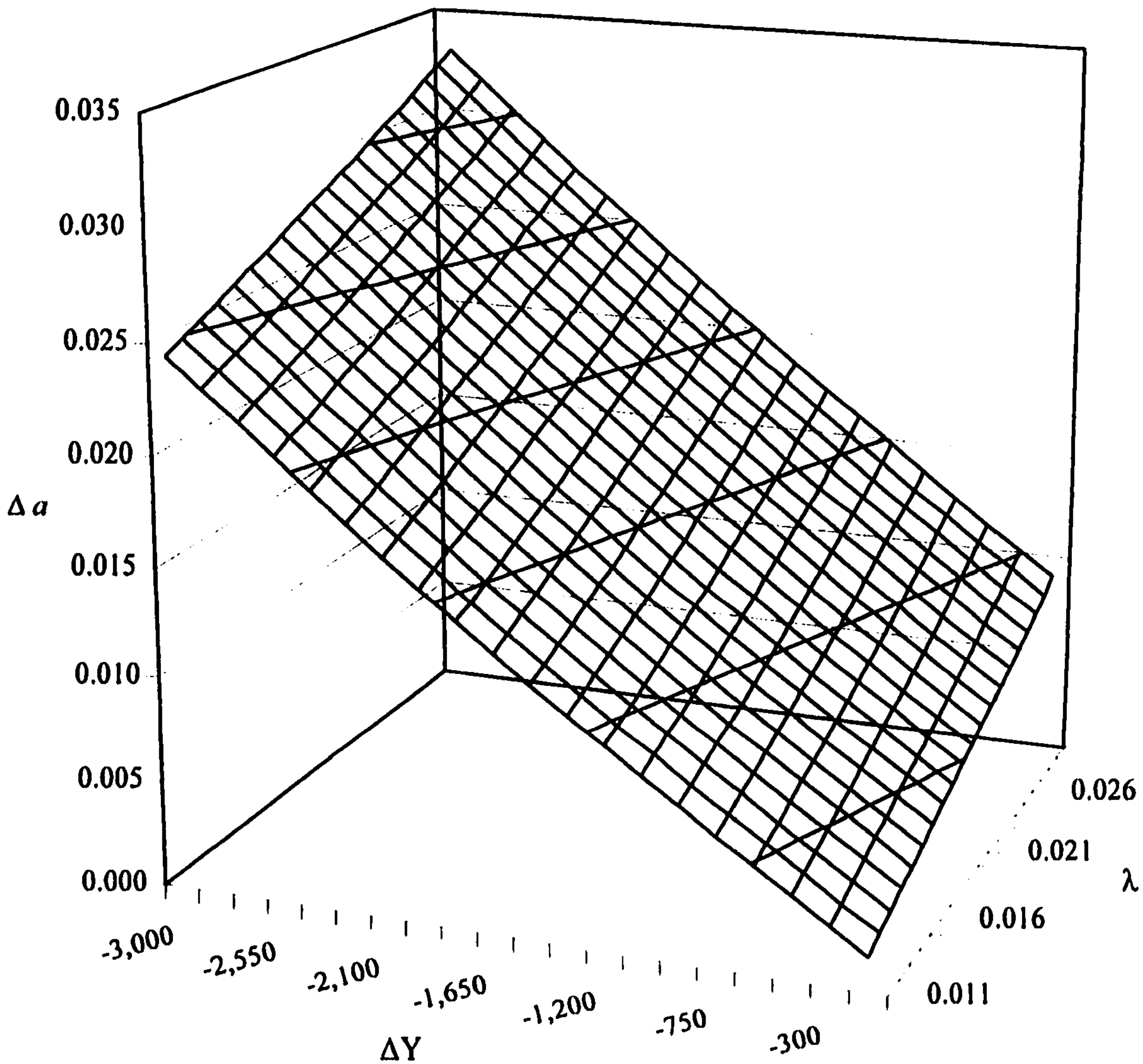

Figure 4: Adjustment in a

Appendix 4A: Partial Derivatives

Partial Derivatives of J(T)

- with respect to λ:

We can develop (5) as

$$J(T)=\frac{E\left[e^{-\delta X}R\mid X<T\right]\Pr(X<T)+E\left[e^{-\delta X}R\mid X=T\right]\Pr(X=T)}{1-E\left[e^{-\delta X}\right]}-\frac{I\,E\left[e^{-\delta X}\right]}{1-E\left[e^{-\delta X}\right]}$$
$$=\frac{H(T)}{1-E\left[e^{-\delta X}\right]}-\frac{I\,E\left[e^{-\delta X}\right]}{1-E\left[e^{-\delta X}\right]}.$$

An increase in λ increases $E\left[e^{-\delta X}\right]$, because $e^{-\delta X}$ is a strictly decreasing function and $F_X(t)$ increases for each $t<T$. Therefore the term involving I will increase.

If we can show that $H(T)$ decreases, we have furthermore to establish that it decreases more than $1-E\left[e^{-\delta X}\right]$. Taking the derivative of $H(T)$ with respect to λ yields

$$\frac{\partial H(T)}{\partial\lambda}=Te^{-\lambda T}\left\{E\left[e^{-\delta X}R\mid X<T\right]-E\left[e^{-\delta X}R\mid X=T\right]\right\}+\left(1-e^{-\lambda T}\right)\frac{\partial E\left[e^{-\delta X}R\mid X<T\right]}{\partial\lambda}.$$

Carrying out the derivatives and expectations and canceling terms results in

$$\frac{\partial H(T)}{\partial\lambda}=-Te^{-\lambda T}\int_0^T e^{-\delta T}r(t)dt+\int_0^T\int_0^\tau r(t)e^{-\delta t}dt\,e^{-\lambda\tau}d\tau-\int_0^T\int_0^\tau r(t)e^{-\delta T}dt\,\lambda\tau\,e^{-\lambda\tau}d\tau$$
$$=-\frac{\partial\Pr(X=T)}{\partial\lambda}\,E\left[e^{-\delta X}R\mid X=T\right]+\frac{\partial E\left[\left(1-e^{-\lambda T}\right)e^{-\delta X}R\mid X<T\right]}{\partial\lambda}.$$

The first term will be negative, but the second term will be positive and their relative size will depend on the size of λ, T, and the entire time path of $r(t)$. Therefore $J_\lambda(T)$ cannot be signed.

- with respect to *I*:

$$J_I = -\frac{\lambda + \delta e^{-(\lambda+\delta)T}}{\phi} \leq 0.$$

- with respect to *a*:

$$J_a = (\lambda + \delta)\lambda \int_0^T \int_0^\tau y(t)\, e^{-\delta t} dt\, e^{-\lambda\tau} d\tau/\phi + (\lambda + \delta)\, e^{-\lambda T} \int_0^T y(t) e^{-\delta t} dt/\phi \geq 0.$$

CHAPTER 5. GENERAL CONCLUSION

This dissertation is devoted to the economic analysis of pesticide regulation in U.S. apple production. Starting from a partial-equilibrium model for the multiproduct firm, it is shown how quality and market allocation effects can be incorporated into a regional assessment of pesticide regulation. In this model estimates of supply and demand elasticities in the markets to be considered are needed to assess the welfare impacts caused by pesticide use cancellations. Regional supply elasticities, U.S. level demand elasticities, and net import elasticities are estimated using a regional econometric model.

The assessment shows that it is important to consider the close links between the market for fresh and processed apples. In general, welfare losses are larger in the high-value fresh market, where consumer experience large surplus losses because of price increases and supply decreases. The EBI fungicides and captan are the economically most important fungicides. Total surplus losses due to a ban on these pesticides are estimated $5.8 mill. and $2.6 mill., respectively. Mancozeb is another fungicides of significant economic importance and the two most important herbicides are glyphosate and simazine, a ban on which would imply losses of $9.6 mill. and $8.0 mill. Regional distribution impacts of pesticide bans are also significant. Following a ban on captan, growers in the western United States would benefit, while growers in other regions would lose. In addition, it is shown that long-run impacts can be considerably larger than short-run impacts because supply responses become more elastic and orchards leave production.

Economic assessments of regulatory actions such as a ban on pesticide use rely frequently on expert opinion to derive impact estimates. Chapter 3 shows how impact distributions can be derived from a dispersed collection of expert opinion arising in form of probability estimates over a finite number of intervals. A method of deriving distributions of economic-surplus changes is proposed, and the distributions of welfare changes are ordered using a nonparametric test that compares distributions in the FSD and SSD sense.

This procedure is implemented in the topical study of banning organophosphates (OPs) in U.S. apple production. Results show that marginal-cost impacts are considerably larger when banning all OPs versus banning one OP only, namely azinphos-methyl (APM). When analyzing welfare impacts of technology restrictions, one must not only consider supply function shifts but also changes in the demand function. It is found that if the average willingness to pay for apples not treated with OPs increases sufficiently, the distribution of welfare impacts after banning all OPs will be superior to the one after banning APM only.

Apple production systems are characterized by the long-term investment decision of orchard planting. Chapter 4 turns to the issue of how pesticide regulation can influence this decision and hence the long-run equilibrium of the industry. It introduces a model that permits deriving the optimal orchard age for orchard replacement, acknowledging explicitly the orchard survival probability that can be affected by pesticide regulation. This framework is applied in the analysis of impacts resulting from a ban on antibiotics use. Changes in the decision to replant are derived, and the model is embedded in an industry equilibrium to facilitate the estimation of welfare impacts. In the case of banning antibiotics in apple production, welfare losses are estimated at about $320 mill.

This dissertation addresses several important issues that arise in the assessment of economic impacts of pesticide regulation in apple production. Several other topics remain to future research. A more explicitly dynamic model would be desirable to endogenize changes in agro-ecosystems and to estimate long-term effects of changes in pest management. Also, assessments should pay greater attention to consumers and changes in the product demand. In regard to the study of welfare changes under uncertainty, it would be interesting to extend the framework of combining expert opinion over impact parameters in a way that allows deriving multivariate impact distributions.

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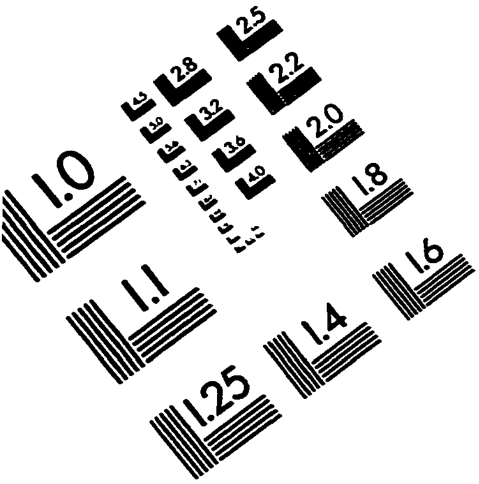
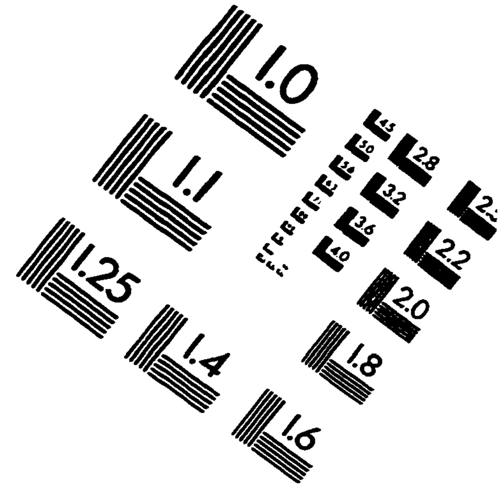
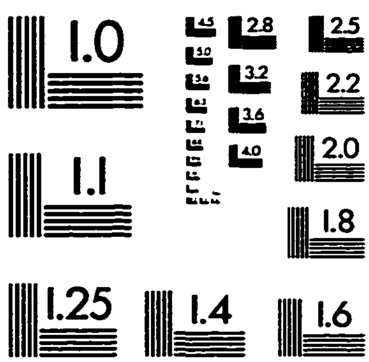
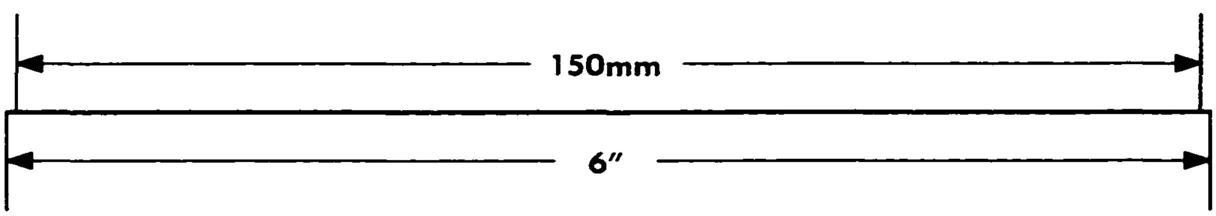
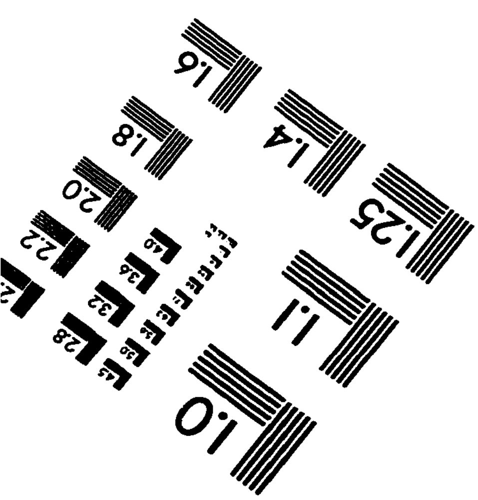
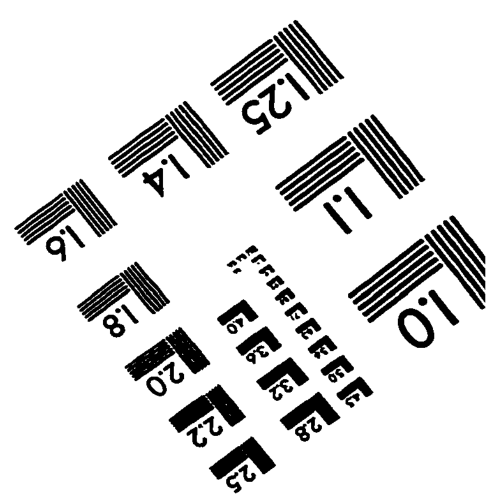
Most importantly I would like to thank my family and my friends whose support and encouragement carried me through all stages of my education.

IMAGE EVALUATION TEST TARGET (QA-3)





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