An Application of the Rational Expectations Hypothesis in the U.S. Beekeeping Industry

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A national beekeeping-industry model, assuming rational expectations, is presented. Consistent and asymptotically efficient estimates are obtained by a modified two-step two-stage least squares method. Based on parameter estimates, elasticities, and likelihood functions, a previously estimated modified adaptive expectations model explains industry behavior better than the rational expectations model. Simulation analyses of the models suggest the direction of the impacts of an ineffective federal honey support program from 1982 through 1985 is similar but the magnitudes are varied. The rational expectations model indicates the decrease in beekeepers' revenue in this period is larger than the decrease identified by the modified adaptive expectations model.

Economic agents make decisions based on their current knowledge of supply, price, and demand factors, as well as their expectations about the future. Various price and profit expectation models have been developed to relate the unobservable expectation model variables to observable model variables. In an adaptive expectations model, the current expected price is a function of the expected price of last year and a ratio of the difference between the previous period's actual price and the expected price (Nerlove; Askari and Cummings). An extrapolative expectations model assumes that economic agents form their expectations by extrapolating their price and profit experience (Labys, pp. 40–41). The rational expectations method of interpreting an agent's use of available information in decision making implies that economic agents know the system structure in which they are operating. The expectations formed are consistent with this structure (Muth).

A number of studies have applied the rational expectations hypothesis to models of agricultural products (Goodwin and Sheffrin; Shonkwiler and Emerson; Tegene, Huffman, and Miranowski; Shonkwiler; Zanias; Shideed, Brannen, and Glover). Each study embodies the rational expectations hypothesis into a standard linear economic model. Aradhyula and Holt, and Antonovitz and Green have extended the rational expectations hypothesis to include higher moments.

Incorporating the hypothesis into an economic model becomes complex if the model contains dynamic structures including multiperiod forecasts, lagged endogenous variables, serial correlation of the error term, or nonlinearities. Analytical solutions, such as that developed by Wallis, become complicated as model nonlinearities and dynamic structures are introduced. Full information maximum likelihood (FIML) estimates, as suggested by Fair and Taylor, will result in asymptotically efficient estimates. However, they could provide inconsistent estimates of all system parameters if a single misspecification is present in an equation. In addition, FIML estimation is computationally expensive with complex model structures. Two-step two-stage least squares (2S2SLS), an instrumental-variables technique developed by Cumby, Huizinga, and Obstfeld, is an extension of McCallum's estimation procedure. The method corrects for serial correlation of the error term, which may be inherent in the model structure or introduced because of the dating of the expectational regressors.

Some authors make a comparison of model estimation or model performance under alternative expectation assumptions (Goodwin and Sheffrin; Shonkwiler; Shideed and White; Antonovitz and Green). However, models with different assump-

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tions cannot be compared directly since one model cannot be obtained from the other by imposing appropriate restrictions. Rather, non-nested testing procedures have been developed to discriminate among separate models. Antonovitz and Green apply the *J* test to evaluate non-nested models. The Atkinson test, applied to linear models whose reduced form can be calculated, nests the non-nested models into a general model. Restrictions on the nested model are tested to determine the appropriate model specification. Alternatively, Pesaran suggests the likelihood ratio test or Lagrange multiplier test can be used to test alternative hypotheses. Pesaran and Deaton extended the Pesaran results so that nonlinear systems of equations can be analyzed, provided the systems can be estimated by FIML techniques. No tests have been developed to evaluate non-nested nonlinear models that are not estimated by FIML techniques.

This paper presents an application of the rational expectations hypothesis in a dynamic simultaneous nonlinear-equation model of the U.S. beekeeping industry. Producers and processors form price and profit expectations as they make decisions concerning colony level, product supply, product demand, and market allocation. These expectations are particularly important given the existence of the federal honey support program. The model is estimated using a modification of the 2S2SLS technique. These estimates are compared with the three-stage least squares (3SLS) estimates of a model of the industry assuming modified adaptive expectations (Willett and French). Non-nested testing, such as the Atkinson technique and the test suggested by Pesaran and Deaton, is not appropriate due to the beekeeping models' nonlinearities and the estimation technique. Rather, each model's coefficients and elasticities are compared.

The paper is divided into three sections. First, the model structure of the beekeeping industry, assuming rational expectations, is presented. Next, the two-step two-stage least squares method of estimation and its modification are discussed. Model estimates are identified. Finally, the estimates and elasticities of the model, assuming rational expectations and the previously estimated modified adaptive expectations model, are analyzed. The impacts of changes in the federal support program using the two models are compared. At issue is whether the extra expense required to estimate rational expectations models that incorporate nonlinearities, lagged endogenous variables, multiperiod forecasts, or two different time horizons is warranted and whether policy implications are consistent between the two models.

Theoretical Model Structure

The Concept of Rational Expectations

Expectations are based on the amount and quality of information, and the way information is used. Under the assumption of rational expectations, information is used and expectations are formed according to the relevant structure of the economic model. The rational expectations hypothesis equates an economic agent's subjective expectations to the mathematical conditional expectations of these variables. Actual values and expectations can be different because of unpredictable uncertainty in the system. Hence, the existence of perfect foresight is not asserted by the rational expectations hypothesis.

Letting I_{t-i} be the information set available to economic agents at time $t - i$ $(i \geq 0)$; $E[X_{t+j}/I_{t-i}]$ be the conditional expectation for the random variable, X_{t+j} $(j \geq 0)$, given the information available at time $t - i$; and ${}_{t-i}X^{e}{}_{t+j}$ be the subjective expectation of X_{t+j} given the information available at time $t - i$, the rational expectations hypothesis can be formalized as

$$\text{(a)} \qquad {}_{t-i}X^{e}{}_{t+j} = E[X_{t+j}/I_{t-i}].$$

The forecast error, ϵ_{t+j}, is defined as

$$\text{(b)} \qquad \epsilon_{t+j} = X_{t+j} - E[X_{t+j}/I_{t-i}].$$

The conditional expectation of the forecast error is zero. Rewriting equation (b) and substituting yields the rational expectations hypothesis, written as

$$\text{(c)} \qquad {}_{t-i}X^{e}{}_{t+j} = X_{t+j} - \epsilon_{t+j}.$$

Hence, under the assumption of rational expectations, the expectation of the random variable, X_{t+j}, given the information available at time $t - i$, is equal to the random variable and a mean-zero forecast error uncorrelated with any variable in the information set $t - i$.

Rational Expectations in the U.S. Beekeeping-Industry Model

The primary products of the beekeeping industry are honey, beeswax, and pollination services. Primary production inputs include packages of bees and queen bees, transportation services, extraction and handling equipment, and labor. As discussed by Willett and French, optimal input and output rates are determined by maximizing expected net revenue over a future time horizon subject to the production function. Supply functions and input demand functions, which express quantities supplied (or demanded) as functions of colony numbers and current prices, are based on the model's assumptions about expectations. Nine of the 13 stochastic model equations, presented by Willett and French, include modified adaptive expectations that must be altered to convert the model to rational expectations. Conversion implies that equation (a) specifies how expectations are formed.

Each model relationship will be discussed. Model equations and variable definitions are presented in Tables 1 and 2, respectively. Exogenous variables are underlined in Table 2. An asterisk indicates an expectation of this variable is included in the model. A double asterisk indicates the variable is a model parameter.

Investment in Colonies. Constraints were imposed on the colony-response function, equation (3.0), to convert the relationship from a function of a series of expected prices to a function of the expected future values of profitability for the three major beekeeping products: honey, pollination services, and bee production. In the final empirical specification, the profitabilities are combined into a single average measure (*FACM*) for each year. The expectations for the current year and future year (${}_{t-1}FACM^{e}{}_{t}$ and ${}_{t-1}FACM^{e}{}_{t+1}$), defined according to the assumptions of strict rational expectations in equation (a), are used. The profitability of each specialty is defined by equations (3.4), (3.5), and (3.6).

Honey and Wax Supply. These relationships, equations (4.0) and (5.0), remain unchanged under the assumption of rational expectations. Beekeepers' honey supply (*QHF*) is based on an evaluation of the relative profitability of the three major products and the current level of colonies. The variable *X* is used to measure a possible shift in supply under an effective support program. Wax supply (*QWX*) is proportional to honey output.

Supply and Demand for Pollination Services. The supply function of pollination services, equation (6.0), is expressed as a price-dependent function since the quantity of pollination services (QPO_C) is entered exogenously. This price ($PPOD_C$) is a function of the price of the service charged in the previous year, the quantity of services demanded (QPO_C), the expected availability of colonies to provide these services (${}_{t-1}COL_{l}{}^{e}{}_{t}$), the expected price received for honey (${}_{t-1}PHMAXD^{e}{}_{t}$), and a time trend. Note that all expectations are defined according to the assumption of rational expectations.

Supply and Demand for Package Bees and Queens. The key factor in determining the price for packages ($PPKD_C$) is the subjective expectation of the price beekeepers will receive for their honey output (${}_{t-1}PHFD^{e}{}_{t}$), as seen in equation (7.0). Equation (8.0) indicates the beekeepers' price-setting relationship for queens ($PQND_C$) is a function of the current price set for package bees and the movement of queens relative to colony numbers (*QQNCOL*). Packages of bees and queen bees are demanded by beekeepers to begin new colonies, replace colonies that have expired, or replace poor-performing colonies. The demands for package bees and queens are proportional to the number of colonies, yet the demands vary with the product price, the expectation of the price received for honey, the effect of the support program, and shifts over time, as seen in equations (9.0) and (10.0). Complementarity in the demand is reflected by including quantity ratios (*QQNCOL* and *QPKCOL*) in the equations.

Allocation of Honey between Processing and the CCC. Beekeepers allocate their honey to the Commodity Credit Corporation (*AHC*) or to the processor based on the ratio of the support price to the domestic honey price (*PHSFARD*). The portion that does not go to the federal government goes to the processor for sale, as described by equations (11.0) through (11.3).

Processor Demand for Honey. The processor demand for domestic honey, equation (12.0), is expressed as a price-dependent function of the quantity of honey (*QSHPM*), an index of processing costs (*ICHPD*), and the price of imported honey (*PHID*). Since processors purchase honey from beekeepers, process the honey, and then sell the honey, it is reasonable to include the price at which processors expect to sell the honey (${}_{t-1}PHRDF^{e}{}_{t}$) and processors' expectations of honey sales (${}_{t-1}DHM^{e}{}_{t}$). In addition, the demand shift variables, *X* and *DUM*73, are incorporated to account for a shift in demand away from domestic honey, which occurred in the 1980s when the support price increased and stayed above the market price, and an upward shift in the demand for honey, which occurred in 1973, respectively.

The factors affecting the demand for imported honey (*IHM*), equation (13.0), are similar to those that determine the demand for U.S.-produced honey. An increase in the price of imported honey (*PHID*) would cause processors to decrease their demand for imported honey, while an increase in the price of domestic honey (*PHMAXD*) would lead processors to shift their demand for imported honey, ceteris paribus. The price at which the processors can expect to sell the honey (${}_{t-1}PHRDF^{e}{}_{t}$) would also affect the demand for imported honey. Processors' expectation of honey sales (${}_{t-1}DHM^{e}{}_{t}$) was not sig-

Table 1. U.S. Beekeeping Industry Model Assuming Rational Expectations[a]

Colony Response

(3.0) $\mathit{COL}_{It} = \beta_{30} + \beta_{31}\mathit{COL}_{It-1} + \beta_{32}\,[(0.5)*{}_{t-1}\mathit{FACM}^{e}_{t} + (0.5)*{}_{t-1}\mathit{FACM}^{e}_{t+1}]$

(3.1) $\mathit{FACM}_t = (1/3) * (\mathit{FHOPMT}_t + \mathit{FPOPMT}_t + \mathit{FPKPMT}_t)$

Product Supply and Demand

Honey profitability:

(3.4) $\mathit{FHOPMT}_t = (\mathit{PHMAXD}_t*\mathit{WHOHO} + \mathit{PWXD}_t*\mathit{WWXHO} + \mathit{PPOD}_{Ct}*\mathit{WPOHO} + \mathit{PPKD}_{Ct}*\mathit{WPKHO} + \mathit{PQND}_{Ct}*\mathit{WQNHO})/(\mathit{PPKD}_{Ct}*\mathit{QPKHO} + \mathit{PQND}_{Ct}*\mathit{QQNHO} + \mathit{CHOPXD}_t)$

Bee-Production profitability:

(3.5) $\mathit{FPKPMT}_t = (\mathit{PHMAXD}_t*\mathit{WHOPK} + \mathit{PWXD}_t*\mathit{WWXPK} + \mathit{PPOD}_{Ct}*\mathit{WPOPK} + \mathit{PPKD}_{Ct}*\mathit{WPKPK} + \mathit{PQND}_{Ct}*\mathit{WQNPK})/(\mathit{PPKD}_{Ct}*\mathit{QPKPK} + \mathit{PQND}_{Ct}*\mathit{QQNPK} + \mathit{CPKPXD}_t)$

Pollination profitability:

(3.6) $\mathit{FPOPMT}_t = (\mathit{PHMAXD}_t*\mathit{WHOPO} + \mathit{PWXD}_t*\mathit{WWXPO} + \mathit{PPOD}_{Ct}*\mathit{WPOPO} + \mathit{PPKD}_{Ct}*\mathit{WPKPO} + \mathit{PQND}_{Ct}*\mathit{WQNPO})/(\mathit{PPKD}_{Ct}*\mathit{QPKPO} + \mathit{PQND}_{Ct}*\mathit{QQNPO} + \mathit{CPOPXD}_t)$

Farm price maximum:

(3.7) $\mathit{PHMAXD}_t = \mathrm{MAXIMUM}(\mathit{PHFD}_t, \mathit{PHSD}_t)$

Honey supply:

(4.0) $\mathit{QHF}_t = \beta_{40} + \beta_{41}\mathit{COL}_{It} + \beta_{42}\mathit{FHOPMT}_t + \beta_{43}\mathit{FPKPMT}_t + \beta_{44}\mathit{FPOPMT}_t + \beta_{45}X_t$

Wax supply:

(5.0) $\mathit{QWX}_t = \mathit{WXHOR}_t * \mathit{QHF}_t$

Pollination price-setting:

(6.0) $\mathit{PPOD}_{Ct} = \beta_{60} + \beta_{61}\,\mathit{PPOD}_{Ct-1} + \beta_{62}\,\mathit{QPO}_{Ct} + \beta_{63}\,{}_{t-1}\mathit{COL}_{I}{}^{e}_{t} + \beta_{64}\,{}_{t-1}\mathit{PHMAXD}^{e}_{t} + \beta_{65}\,\mathit{TRND}_t$

Package price-setting:

(7.0) $\mathit{PPKD}_{Ct} = \beta_{70} + \beta_{71}\,{}_{t-1}\mathit{PHFD}^{e}_{t}$

Queen price-setting:

(8.0) $\mathit{PQND}_{Ct} = \beta_{80} + \beta_{81}\,\mathit{PPKD}_{Ct} + \beta_{82}\,\mathit{QQNCOL}_t$

Package bee demand:

(9.0) $\mathit{QPKCOL}_t = \beta_{90} + \beta_{91}\,\mathit{PPKD}_{Ct} + \beta_{92}\,{}_{t-1}\mathit{PHMAXD}^{e}_{t} + \beta_{93}\,\mathit{QQNCOL}_t + \beta_{94}\,X_t + \beta_{95}\,\mathit{DUM65}_t$

Queen demand:

(10.0) $\mathit{QQNCOL}_t = \beta_{100} + \beta_{101}\,\mathit{PQND}_{Ct} + \beta_{102}\,\mathit{QPKCOL}_t + \beta_{103}\,{}_{t-1}\mathit{PHMAXD}^{e}_{t} + \beta_{104}\,X_t + \beta_{105}\,\mathit{TRND}_t$

Allocation of honey between CCC and processors:[b]

(11.0) $\mathit{QHC}_t = \mathit{AHC}_t * \mathit{QHF}_t$

(11.1) $\mathit{AHC}_t = \mathit{POS}(\beta_{110} + \beta_{111}\,\mathit{PHSFARD}_t)$

(11.2) $\mathit{PHSFARD}_t = \mathit{PHSD}_t/\mathit{PHFD}_t$

(11.3) $\mathit{QHP}_t = (1 - \mathit{AHC}_t) * \mathit{QHF}_t$

Processor demand for honey;

(12.0) $\mathit{PHFD}_t = \beta_{120} + \beta_{121}\,\mathit{QSHPM}_t + \beta_{122}\,\mathit{ICHPD}_t + \beta_{123}\,{}_{t-1}\mathit{PHRDF}^{e}_{t} + \beta_{124}\,{}_{t-1}\mathit{DHM}^{e}_{t} + \beta_{125}\,\mathit{PHID}_t + \beta_{126}\mathit{DUM73}_t + \beta_{127}\,X_t$

Processor demand for imported honey:

(13.0) $\mathit{IHM}_t = \beta_{130} + \beta_{131}\,\mathit{QSHPM}_t + \beta_{132}\,\mathit{PHMAXD}_t + \beta_{133}\,{}_{t-1}\mathit{PHRDF}^{e}_{t} + \beta_{134}\,\mathit{PHID}_t + \beta_{135}\,\mathit{DUM73}_t + \beta_{136}\,X_t$

Wax demand:

(14.0) $\mathit{PWXD}_t = \beta_{140} + \beta_{141}\,\mathit{QWXM}_t + \beta_{142}\,{}_{t-1}\mathit{FHOPMT}^{e}_{t} + \beta_{143}\,\mathit{PWXID}_t + \beta_{144}\,X_t$

(14.1) $\mathit{QWXM}_t = \mathit{QWX}_t/M_t$

Processors' Marketing

Supply of processed honey:

(16.0) $\mathit{QDHMM}_t = \beta_{160} + \beta_{161}\,(\mathit{PHRDF}_t - {}_{t}\mathit{PHRDF}^{e}_{t+1}) + \beta_{162}\,\mathit{QSHPM}_t + \beta_{163}\,(\mathit{PHMAXD}_t - {}_{t}\mathit{PHMAXD}^{e}_{t+1}) + \beta_{164}\,\mathit{TRND}_t + \beta_{165}\,X_t$

Demand for processed honey:

(17.0) $\mathit{PHRDF}_t = \beta_{170} + \beta_{171}\,\mathit{DHM}_t + \beta_{172}\,\mathit{DUM73}_t + \beta_{173}\,\mathit{TRND73}_t + \beta_{174}\,X_t$

(17.1) $\mathit{DHM}_t = \mathit{QDHMM}_t + \mathit{IHM}_t - \mathit{EH}_t/M_t$

Carry-over stocks:

(18.0) $\mathit{SHP}_{t+1} = \mathit{QHP}_t + (\mathit{IHM}_t * M_t) + \mathit{SHP}_t - (\mathit{DHM}_t * M_t) - \mathit{EH}_t$

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[a] All expectations are formed according to the assumptions of strict rational expectations as defined by equation (a) in the text.

[b] The *POS* function in TSP (Time Series Processor) takes the value in the parentheses or 0, whichever is larger. The *AHC* function is restricted such that $0 \leq \mathit{AHC} \leq 1$.

Table 2. Model Variable Definitions[a]

Name	Definition	Measure
AHC	Allocation of honey to the CCC	(proportion)
$\underline{\mathit{CHOPXD}}$	Exogenous input costs for honey producer	(\$/colony)
$^{*}\mathit{COL}_t$	Industry colonies	(thousands)
$\underline{\mathit{Constant}}$	Intercept	(1)
$\underline{\mathit{CPKPXD}}$	Exogenous input costs for package-bee producer	(\$/colony)
$\underline{\mathit{CPOPXD}}$	Exogenous input costs for pollination producer	(\$/colony)
**DHM*	Disappearance of honey	(lbs/person)
$\underline{\mathit{DUM}65}$	Dummy in 1965 and after	(0 or 1)
$\underline{\mathit{DUM}73}$	Dummy in 1973 and after	(0 or 1)
$\underline{\mathit{EH}}$	Exports of honey	(million lbs)
**FACM*	Profitability ratio for all products	(dimensionless)
**FHOPMT*	Profitability ratio for honey production	(dimensionless)
FPKPMT	Profitability ratio for package-bee production	(dimensionless)
FPOPMT	Profitability ratio for pollination services	(dimensionless)
I	Information set	(dimensionless)
$\underline{\mathit{ICHPD}}$	Index of costs of honey processing	(1972 = 100)
$\underline{\mathit{IHM}}$	Imports of honey	(lbs/person)
$\underline{\mathit{M}}$	Population	(millions)
**PHFD*	Farm price of honey	(72\$/lb)
$\underline{\mathit{PHID}}$	Price of U.S. honey imports	(72\$/lb)
**PHMAXD*	Maximum farm price of honey	(72\$/lb)
**PHRDF*	Retail price of honey	(72\$/lb)
$\underline{\mathit{PHSD}}$	Price of honey support	(72\$/lb)
PHSFARD	Support to farm honey price ratio	(dimensionless)
PPKD_C	Price of package bees (California)	(72\$/lb)
PPOD_C	Price of pollination services (California)	(72\$/service)
PQND_C	Price of queen bees (California)	(72\$/bee)
PWXD	Price of wax	(72\$/lb)
PWXID	Price of wax imports	(72\$/lb)
QDHMM	Quantity of domestic honey marketed	(lbs/person)
QHC	Quantity of honey to the CCC	(million lbs)
QHF	Quantity of honey	(million lbs)
QHP	Quantity of honey to processors	(million lbs)
QPKCOL	Ratio of packages to colonies	(lbs/colony)
***QPK(J)*	Packages used by (*J*) producer, where *J* = *HO* honey *PK* package bees *PO* pollination	(lbs/colony)
$\underline{\mathit{QPO}_C}$	Quantity of pollination services (California)	(thousand services)
QQNCOL	Ratio of queens to colonies	(bees/colony)
***QQN(J)*	Queens used by (*J*) producer, where *J* is as in *QPK(J)*	(bees/colony)
QSHPM	Total domestic quantity of honey at the processor	(lbs/person)
QWX	Quantity of wax	(million lbs)
QWXM	Quantity of wax	(lbs/person)
SHP	Stocks of honey	(million lbs)
$\underline{\mathit{TRND}}$	Linear time trend	(year, 1952 = 3)
$\underline{\mathit{TRND}73}$	Time trend beginning in 1973	(year, 1973 = 1)
***WHO(J)*	Honey produced by (*J*) producer, where *J* is as in *QPK(J)*	(lbs/colony)
***WPK(J)*	Packages produced by (*J*) producer, where *J* is as in *QPK(J)*	(lbs/colony)
***WPO(J)*	Pollination services produced by (*J*) producer, where *J* is as in *QPK(J)*	(services/colony)
***WQN(J)*	Queens produced by (*J*) producer, where *J* is as in *QPK(J)*	(bees/colony)
***WWX(J)*	Wax produced by (*J*) producer, where *J* is as in *QPK(J)*	(lbs/colony)
$\underline{\mathit{WXHOR}}$	Wax-to-Honey production ratio	(lbs/lbs)
$\underline{\mathit{X}}$	Dummy variable for support-program effectiveness	(0 or \$72/lb)

[a] Exogenous variables are underlined. An asterisk indicates an expectation of this variable is included in the model. A double asterisk indicates the variable is a model parameter.

nificant in the empirical specification. The demand shift variables, X and $DUM73$, are included for reasons described previously.

Farm-Level Demand for Beeswax. The demand for wax, equation (14.0), indicates that as the expected profitability of honey production increases $({}_{t-1}FHOMPT^e{}_t)$, one might anticipate expansion in colonies and an increase in the demand for wax frame foundations. An increase in the price of imported wax (*PWXID*) would increase the demand for wax produced domestically. The demand shift variable, X, is included to reflect the impact of the federal support program.

Demand Facing Honey Processors and Their Market Allocation. Price-taking processors determine the quantity of the total domestic supply of processed product to be supplied to the current market and the quantity to be held in inventory for future sales. Processors have a total per capita supply of domestic honey (*QSHPM*) consisting of honey processed and packaged, and carry-in stocks. It is assumed imports are sold currently with no inventory carry-over. Processors determine their short-run honey supply based on their current costs and their expectation of future costs. Since the raw-product price of honey is the key component of processed honey, its price (*PHMAXD*) is used as a measure of input costs. The prices processors receive for their product and the processors' expectation of future prices will also influence their market allocation. Hence, the short-run supply equation for the processed honey product can be specified as in equation (16.0).

The domestic demand for honey, equation (17.0), is specified as a price-dependent function of the per capita disappearance of honey (*DHM*). Two variables, *DUM73* and *TRND73*, capture the change in consumer tastes and consumers' reaction to the onset of high-level inflation beginning in 1973. The demand for processed honey is also affected by the availability of Commodity Credit Corporation (CCC) stocks since any honey the government distributes competes directly with honey from processors. The variable X is included in the empirical specification to capture the phenomenon. Variables measuring income and honey substitutes were not significant and were omitted from the equation.

The final two model equations are identities that describe the actual disappearance of honey and the level of inventory. Actual disappearance of honey (*DHM*) is equal to the quantity of domestic honey marketed by the processor plus imports less exports. The inventory of honey carried into the next year (SHP_{t+1}) is the sum of stocks brought into the current period, the amount of raw honey purchased by processors from beekeepers, and honey imports less actual disappearance of honey and exports.

The complete model of the U.S. honey industry includes three types of price and profit expectations. The expectations in the model sectors describing the colony response and the product's supply and demand are rational expectations for period t and $t + 1$ based on information available in time $t - 1$. The rational expectations formed in the processors' marketing sector are for period $t + 1$ and are based on information available at time t. These multiperiod forecasts and multiple time periods make estimation of the equations more complex than if one type of expectation had been included.

Model Estimation

Estimation Procedures for Rational Expectations Models

Generally, two methods are used to estimate simultaneous-equation models incorporating rational expectations. The first method, a full information estimation technique, is often used in simpler models. It involves solving for the model's endogenous variables as functions of the expectations, lagged endogenous variables, exogenous variables, and error terms.[1] A conditional expectation of this relationship is taken. The result is an equation for the expectations of endogenous variables as functions of the structural parameters of the model, lagged endogenous variables, and forecasts of the exogenous variables. Substituting this expression into the original structural-model specification yields a partially reduced form of the model. The partially reduced form can be estimated because the current endogenous variables are determined by lagged endogenous variables, current and expected values of the exogenous variables (specified externally to the model), and structural disturbances. Conceivably, the forecasts of the exogenous variables can be estimated simultaneously with the structural model. However, it is quite common to resort to a two-step estimation procedure where the forecasts for the exogenous variables are estimated first by an appropriate maximum-likelihood procedure. These forecasts are substituted into the appropriate equation. A multivariate least squares procedure is used

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[1] For a detailed analysis of this approach, see Wallis. For an application of this method in the case of a supply-and-demand analysis of an agricultural commodity, see Fisher. For an application in the chicken-broiler industry, see Goodwin and Sheffrin.

to obtain consistent and efficient reduced-form coefficients. This technique provides a feasible approach to incorporate the rational expectations hypothesis into a simple standard linear economic model whose purpose is prediction and policy analysis.

However, this approach becomes more complex if the model incorporates dynamic structures that include lagged endogenous variables, multiperiod forecasts, two different time horizons in forming expectations, serial correlation, or model nonlinearities, as in this model of the beekeeping industry. With the introduction of any of these complexities into the model, it is necessary to solve the model for the entire future out to infinity to find the reduced form. Since the complexity of finding this solution escalates with complex dynamic structures, numerical methods have been proposed to solve the model and determine the reduced form prior to estimation. However, these numerical methods themselves are quite involved when model complexities, such as those in this beekeeping model, are introduced.

If the model's parameters are not known, it is necessary to pick values for the parameters and solve the model forward based on these parameter values and some initial conditions. Given the parameters, the optimal path to a convergent and stable solution is found by iterating over initial conditions. The fit of the parameters is determined by the likelihood function and the optimal initial conditions for that set of parameters. The complete process is repeated until the parameters that provide the best fit are found (Fair and Taylor). If the model parameters are known, it is necessary to solve the model for the optimal path (i.e., the one that leads to convergence given the parameter values). The solution is obtained by iterating over initial conditions for the model (Lipton, Poterba, Sachs, and Summers). This iteration procedure alone is quite involved. Because of the complexities involved in numerical solution and estimation methods, an alternative method developed by Cumby, Huizinga, and Obstfeld is used and slightly modified to estimate the coefficients of the model of the beekeeping industry presented here.

This method, two-step two-stage least squares (2S2SLS), is an extension of McCallum's estimation procedure. It is a direct structural estimation method that corrects for serial correlation in the error term, which may be inherent in the model structure or introduced because of the dating of the expectational regressors. In the case of a linear model, Cumby et al. propose a 2S2SLS estimator of

$$\text{(d)}\qquad \mathbf{d} = (\mathbf{Q}'\mathbf{X}\hat{\Omega}^{-1}\mathbf{X}'\mathbf{Q})^{-1}\,\mathbf{Q}'\mathbf{X}\hat{\Omega}^{-1}\mathbf{X}'\mathbf{y},$$

for the general linear model

$$\text{(e)}\qquad \mathbf{y} = \mathbf{Q}f(\delta^*) + \epsilon,$$

where $\mathbf{X}$ is a matrix of instrumental variables. As shown by Cumby et al., the 2S2SLS estimator, $\mathbf{d}$, is a consistent estimator of δ^*. The

(f) (1) plim $\mathbf{d} = \delta^*$ and
(2) $(T^{1/2})(\mathbf{d} - \delta^*)$ converges in distribution to $\mathrm{N}\{0, \operatorname{plim}[(\mathbf{V}'\mathbf{X}/T)\Omega^{-1}(\mathbf{X}'\mathbf{V}/T)]^{-1}\}$,

where $\mathbf{V} = \mathbf{Q}(\partial f/\partial\delta')/\delta^*$.

The first step in obtaining the estimator, $\mathbf{d}$, and its covariance matrix, Ω, is to derive a consistent estimator, $\hat{\Omega}^{-1}$, of Ω. This can be formed as

$$\text{(g)}\qquad \hat{\Omega} = \sum_{L=-N+1}^{N-1} \{(1/T)\sum_{t=1}^{T} \mathbf{X}'_t\hat{\epsilon}_t\hat{\epsilon}_{t-L}\mathbf{X}_{t-L}\},$$

where $\hat{\epsilon}_t$ are the estimated residuals from an application of nonlinear two-stage least squares to the general nonlinear model expressed in equation (e), and N refers to an integer such that a variable observed before period $t - N$ is in the information set. Since equation (g) is the sum of a series of noncontemporaneous covariance matrices, it is not guaranteed to be positive semidefinite when $N > 1$. Some estimated variances and test statistics will be negative when the estimated covariance matrix is not positive semidefinite. Hence, formation of asymptotic confidence intervals and hypothesis testing will be inhibited. The use of spectral methods for the estimation of a positive semidefinite covariance matrix has been suggested by Cumby et al. Rather than use this technique, an alternative method, developed by Newey and West, of formulating a positive semidefinite covariance matrix was used in this analysis. The estimator Newey and West propose is a weighted function of the sample autocovariance matrices

$$\text{(h)}\qquad \Omega\dagger = \sum_{L=-N+1}^{N-1} \{(1/T)\, w(L, N) \sum_{t=1}^{T}\mathbf{X}'_t\hat{\epsilon}_t\hat{\epsilon}_{t-L}\mathbf{X}_{t-L}\},$$

where the weights are a function of L and N and decline as $|L|$, the absolute value of L, increases, as seen in

$$\text{(i)}\qquad w(L, N) = 1 - \frac{|L|}{N}.$$

Newey and West prove that this estimator, $\Omega\dagger$, is positive semidefinite. This positive semidefinite

Table 3. Estimates of the U.S. Beekeeping Industry Model

	Rational Expectations		Modified Adaptive Expectations[a]	
	Coefficient	*t* Statistic	Coefficient	*t* Statistic
Colony				
β_{30}	82.475	(1.612)	139.658	(1.102)
β_{31}	0.936	(124.477)	0.903	(34.323)
β_{32}	165.412	(6.702)	242.299	(3.591)
ρ_{3}	0.259	(4.399)	NA[b]	NA
Honey supply				
β_{40}	120.388	(2.748)	121.935	(3.347)
β_{41}	0.047	(4.306)	0.049	(5.749)
β_{42}	73.836	(1.643)	117.232	(3.989)
β_{43}	−57.815	(−2.228)	−73.478	(−3.687)
β_{44}	−166.104	(−1.687)	−230.157	(−3.571)
β_{45}	−911.922	(−1.822)	−867.201	(−2.079)
Pollination price setting				
β_{60}	3.323	(2.234)	11.063	(4.300)
β_{61}	0.400	(4.317)	0.423	(4.245)
β_{62}	0.004	(4.966)	0.004	(5.377)
β_{63}	−0.0002	(−0.688)	−0.002	(−3.471)
β_{64}	4.949	(5.761)	3.710	(3.465)
β_{65}	−0.104	(−3.408)	−0.191	(−4.341)
ρ_{6}	0.234	(2.078)	NA	NA
Package price setting				
β_{70}	0.477	(9.242)	0.194	(1.639)
β_{71}	8.042	(33.579)	9.442	(19.302)
ρ_{7}	0.453	(10.682)	NA	NA
Queen price setting				
β_{80}	−0.230	(−2.523)	−0.229	(−2.912)
β_{81}	0.860	(19.342)	0.865	(24.562)
β_{82}	3.2082	(3.790)	3.045	(4.326)
Package bee demand				
β_{90}	0.029	(6.435)	0.035	(5.788)
β_{91}	−0.004	(−2.621)	−0.026	(−3.499)
β_{92}	0.061	(2.030)	0.243	(2.944)
β_{93}	0.850	(15.683)	0.933	(10.942)
β_{94}	−0.624	(−3.324)	−0.894	(−3.954)
β_{95}	0.034	(6.810)	0.029	(6.038)
ρ_{9}	0.363	(4.977)	NA	NA
Queen demand				
β_{100}	−0.010	(3.330)	−0.113	(−2.602)
β_{101}	−0.003	(−1.315)	−0.022	(−3.577)
β_{102}	0.291	(6.143)	0.247	(4.205)
β_{103}	0.080	(2.537)	0.289	(4.489)
β_{104}	−0.087	(−0.869)	−0.169	(−1.023)
β_{105}	0.002	(7.955)	0.002	(6.200)
ρ_{10}	0.404	(7.270)	NA	NA
Allocation of honey				
β_{110}	−1.217	(−3.059)	−1.217	(−3.059)
β_{111}	1.441	(4.131)	1.441	(4.131)
Processor demand for honey				
β_{120}	−0.008	(−0.179)	0.263	(4.796)
β_{121}	0.005	(0.332)	−0.004	(−0.393)
β_{122}	−0.001	(−2.922)	−0.003	(−5.714)
β_{123}	0.506	(7.214)	0.249	(3.939)
β_{124}	0.034	(1.480)	0.017	(1.205)
β_{125}	0.463	(8.757)	0.613	(13.629)
β_{126}	0.056	(7.389)	0.098	(8.580)
β_{127}	−0.033	(−0.230)	−0.623	(−2.214)
ρ_{12}	0.596	(4.450)	NA	NA

Table 3. Continued

	Rational Expectations		Modified Adaptive Expectations[a]	
	Coefficient	*t* Statistic	Coefficient	*t* Statistic
Demand for imported honey				
β_{130}	0.694	(14.151)	0.375	(3.570)
β_{131}	−0.129	(−7.588)	−0.143	(−4.735)
β_{132}	2.097	(5.788)	0.827	(1.558)
β_{133}	−1.400	(−7.686)	0.068	(0.282)
β_{134}	−1.923	(−8.661)	−1.699	(−4.035)
β_{135}	0.211	(7.082)	0.143	(2.562)
β_{136}	0.198	(0.361)	2.667	(2.465)
ρ_{13}	−0.075	(−0.613)	NA	NA
Wax demand				
β_{140}	0.188	(8.194)	0.151	(3.447)
β_{141}	−6.301	(−10.812)	−5.713	(−4.930)
β_{142}	0.050	(6.299)	0.055	(2.529)
β_{143}	0.767	(42.045)	0.786	(25.915)
β_{144}	−2.294	(−21.804)	−2.159	(−3.648)
ρ_{14}	0.360	(5.881)	NA	NA
Supply of processed honey				
β_{160}	0.167	(2.542)	−0.295	(−2.287)
β_{161}	0.497	(1.440)	1.179	(2.276)
β_{162}	0.741	(22.818)	0.943	(15.472)
β_{163}	−1.437	(−3.427)	−0.250	(−0.583)
β_{164}	−0.004	(−1.881)	0.006	(2.385)
β_{165}	−5.042	(−4.416)	−5.049	(−4.692)
ρ_{16}	0.707	(7.914)	NA	NA
Demand for processed honey				
β_{170}	0.357	(10.105)	0.423	(17.504)
β_{171}	0.009	(0.318)	−0.043	(−2.257)
β_{172}	0.220	(16.718)	0.213	(21.798)
β_{173}	−0.011	(−6.304)	−0.012	(−9.338)
β_{174}	−0.703	(−1.392)	−0.993	(−2.340)

[a] Modified adaptive expectations estimates are from Willett and French.
[b] NA = not applicable.

covariance matrix can be employed easily to obtain the 2S2SLS estimator, **d**, and its covariance matrix.

This 2S2SLS estimator is applicable to models incorporating rational expectations when residuals are autocorrelated and when instruments are predetermined but not strictly exogenous. The estimator is consistent and asymptotically efficient in its class of instrumental-variable estimators.

Empirical Estimates of the Beekeeping Model

Data from 1952 through 1984 were used in the estimation. Data following 1984 were reserved for out-of-sample prediction tests. Data pertaining to honey quantities, honey prices, and colonies are national values. Cost of production, pollination services, and package bees and queen bees values are California statistics since U.S. values are not published. All monetary values are deflated by the U.S. personal consumption expenditure deflator. One period of correlation among the error terms was allowed. All instruments used in the model estimation are predetermined but not necessarily strictly exogenous. Exogenous instruments are observed at period $t - 1$; strictly predetermined instruments are observed at period $t - 2$.

The equations that contain expectation variables (equations (3.0), (6.0), (7.0), (9.0), (10.0), (12.0), (13.0), (14.0), and (16.0)) were estimated by 2S2SLS, modified by the Newey and West technique. The equations that do not contain expectational variables (equations (4.0), (8.0), and (17.0)) were estimated by two-stage least squares. The allocation of honey to the CCC (equation (11.1)) was estimated by ordinary least squares because of limited data available on the support program's effectiveness. Final model estimates of β and ρ, where ρ is the first-order autocorrelation coefficient introduced in the equations with expectations formed rationally, are presented in Table 3. The coefficients' t statistics are also presented. For ease of

Table 4. Price Elasticities and Flexibilities

	Rational Expectations		Modified Adaptive Expectations[a]	
	Mean	1980 Values	Mean	1980 Values
Colony				
$\epsilon_{COL_l, PHMAXD}$				
(short-run)	0.016	0.016	0.024	0.023
(long-run)	0.251	0.245	0.242	0.237
$\epsilon_{COL_l, FACM^e}$[b]				
(short-run)	0.040	0.041	0.059	0.067
(long-run)	0.623	0.636	0.610	0.687
Supply				
$\epsilon_{QHF, PHMAXD}$	0.091	0.083	0.193	0.182
f_{PPOD_C, QPO_C}				
(short-run)	0.354	0.536	0.410	0.621
(long-run)	0.590	0.893	0.710	1.182
f_{PQND_C, QQN_C}	0.117	0.192	0.111	0.182
$\epsilon_{QDHMM, PHRDF}$	0.188	0.243	0.447	0.575
Demand				
$f_{PWXD, QWXM}$	−0.181	−0.109	−0.164	−0.099
$\epsilon_{QPKCOL, PPKD_C}$	−0.080	−0.058	−0.517	−0.380
$\epsilon_{QQNCOL, PQND_C}$	−0.079	−0.050	−0.580	−0.368
$f_{PHFD, QHPM}$	0.024	0.143	−0.021	−0.012
$\epsilon_{IHM, PHID}$	−2.542	−2.072	−2.246	−1.831
$f_{PHRDF, DHM}$	0.025	0.018	−0.121	−0.085

[a] Modified adaptive expectations elasticities and flexibilities are from Willett and French.
[b] *FACMT2* in model assuming modified adaptive expectations.

comparison, 3SLS estimates of the same model assuming modified adaptive expectations (Willett and French) are presented.

Most estimated coefficients of the model assuming rational expectations are of reasonable magnitude and the correct sign, as determined by the theoretical specifications. However, there are some exceptions. The coefficient β_{121} in the relationship describing the processor demand for honey is positive but not significant. According to the rational expectations assumption, the support program does not affect the processor demand for honey, as seen by β_{127}. In the relationship describing the demand for imported honey, the coefficient for expected price of processed honey, β_{133}, is significant and of questionable sign. Yet, the coefficient for the impact of the support program, β_{136}, is not significant. The coefficient β_{164} indicates there was a decrease in the supply of processed honey over time when one assumes expectations are formed rationally. The modified adaptive expectations hypothesis indicated an increase in the quantity marketed over time. Finally, β_{171}, the coefficient relating the disappearance of honey to the honey price in the relationship for the demand for processed honey, is insignificant.

The log of the likelihood function of the model assuming modified adaptive expectations has a value of 361.408. Assuming rational expectations in the model of the beekeeping industry yields a log of the likelihood function equivalent to 235.821. A comparison of these values indicates the assumption of modified adaptive expectations appears to be more appropriate than the assumption of rational expectations in the beekeeping industry.

Flexibilities and elasticities calculated from the models assuming rational expectations and modified adaptive expectations are presented in Table 4. The values are evaluated at the mean of the data set and at 1980 values. The values for 1980 were chosen because that is the most recent year the federal support program was not effective. Short-run colony responses to price and profitability, $\epsilon_{COL_l, PHMAXD}$ and $\epsilon_{COL_l, FACM^e}$, are slightly less elastic when one assumes rational expectations. Most long-run colony elasticities indicate more responsiveness under the assumption of rational expectations. The conditional supply elasticity for honey, given the level of colonies, $\epsilon_{QHF,\ PHMAXD}$, and the allocation elasticity for honey given the seasonal supply, $\epsilon_{QDHMM,\ PHRDF}$, are less elastic when one assumes rational expectations. More responsiveness, assuming rational expectations, is implied by the flexibility for pollination, $f_{PPOD_C,\ QPO_C}$. However, the price flexibility for queen pricing, $f_{PQND_C,\ QQN_C}$, implies more responsiveness when modified adaptive expectations are assumed.

Under the assumption of rational expectations, the demand elasticities for packages and queens, $\epsilon_{QPKCOL,\ PPKD_C}$ and $\epsilon_{QQNCOL,\ PQND_C}$, are less elastic, while the demand for imported honey, $\epsilon_{IHM,\ PHID}$, is more elastic. The demand price flexibilities for processor demand for honey, $f_{PHFD,\ QHPM}$, and the demand for processed honey, $f_{PHRDF,\ DHM}$, are misleading due to incorrect signs on coefficients β_{121} and β_{171}. The wax price flexibility is larger when one assumes rational expectations.

Policy Analysis and Interpretations

The federal honey price-support program was essentially ineffective prior to 1982. At that time, the market price was below the support price. Producers found it more profitable to forfeit their honey to the CCC than to sell it on the market. As a result, honey imports increased. The model assuming rational expectations was used to analyze the impacts on endogenous variables of assuming the price support had continued below the market price from 1982 through 1985. Additional years were omitted because of further changes in the support program. These impacts are compared with a similar analysis presented by Willett and French.

Table 5 presents the predicted values of key endogenous variables with and without the support program for the model. These predictions include the random disturbance terms since these factors would not change under alternative scenarios.

Table 5 suggests that the direction of change in the endogenous variables of each model is similar. However, the simulation using the rational expectations model indicates a smaller decrease in the number of colonies (*COL*) and a smaller increase in the price of honey received by beekeepers (*PHFD*) than suggested by the modified adaptive expectations model. The rational expectations model suggests that beekeepers' revenue decreases from 1982 through 1985. The modified adaptive expectations model suggests revenue decreases from 1982 through 1984 but increases again in 1985. When no support is assumed, the modified adaptive expectations model suggests the total revenue for 1982 through 1985 is slightly lower than when the support program was effective. However, the rational expectations model indicates a decrease in revenue of more than $30 million had the support program remained ineffective. The conclusion using the rational expectations model is consistent with the conclusion drawn from the simulations of the modified adaptive expectations model. That is, given the $246 million expense of the federal support program from 1982 through 1985 (Hoff and Phillips), both models suggest the honey support program was an ineffective means of supporting honey prices during the period of analysis.

Non-nested tests between a model of the beekeeping industry assuming rational expectations and a model of the industry assuming modified adaptive expectations could determine if one expectation structure is more relevant. However, non-nested tests are applicable to nonlinear models that are estimated by FIML techniques. They are not applicable to nonlinear models estimated by two different methods, as in this case of the model of the beekeeping industry.

A comparison of the beekeeping-model coefficients assuming rational expectations and coefficients of a previously estimated beekeeping model assuming modified adaptive expectations leads one to question the use of a rational expectations assumption for industry behavior. Furthermore, a comparison of the log of the likelihood function of the two models supports this conclusion. Price elasticities and flexibilities suggest that colony response is less elastic and supply elasticities and supply flexibilities are somewhat smaller under the rational expectations assumption. The demands for packages and queens are less elastic, while the demand for imported honey is more elastic, under the assumption of rational expectations. Simulation analyses of the models suggest the direction of the impacts of an ineffective federal honey support program from 1982 through 1985 is similar but the magnitudes are varied. The rational expectations model indicates the sum of beekeepers' revenue from 1982 through 1985 decreased more than indicated by the modified adaptive expectations model. However, the overall conclusion that the federal support program was an ineffective means of supporting beekeepers' revenue from 1982 through 1985 is supported. Given these results, the extra expense required to estimate rational expectations models that incorporate nonlinearities, lagged endogenous variables, multiperiod forecasts, or two different time horizons is warranted only if it is clear industry participants form their expectations rationally.

Table 5. Comparison of Predicted Values (Including Disturbances) of Endogenous Variables with and without the Support Program, 1982–85

	Year	Support	No Support (Modified Adaptive Expectations)	No Support (Rational Expectations)
Colony, COL_l	1982	4250.0	4250.0	4250.0
(equation 3.0)	1983	4275.0	4272.0	4275.0
	1984	4300.0	4291.0	4298.8
	1985	4325.0	4307.8	4318.7
Honey supply, QHF	1982	230.0	230.4	230.0
(equation 4.0)	1983	205.0	217.0	205.0
	1984	165.1	187.8	165.1
	1985	150.1	186.4	150.1
Pollination price, $PPOD_C$	1982	9.285	9.285	9.285
(equation 6.0)	1983	8.843	8.774	8.843
	1984	8.683	8.592	8.627
	1985	8.686	8.507	8.490
Package price, $PPKD_C$	1982	2.929	2.929	2.929
(equation 7.0)	1983	2.580	2.587	2.581
	1984	2.404	2.505	2.418
	1985	2.554	2.790	2.551
Queen price, $PQND_C$	1982	2.499	2.504	2.502
(equation 8.0)	1983	2.414	2.423	2.414
	1984	2.311	2.421	2.339
	1985	2.151	2.370	2.159
Package demand, $QPKCOL$	1982	0.172	0.177	0.175
(equation 9.0)	1983	0.169	0.179	0.169
	1984	0.145	0.175	0.160
	1985	0.119	0.154	0.133
Queen demand, $QQNCOL$	1982	0.132	0.134	0.133
(equation 10.0)	1983	0.128	0.129	0.128
	1984	0.123	0.131	0.128
	1985	0.111	0.116	0.115
Allocation, AHC	1982	0.324	0.000	0.000
(equation 11.0)	1983	0.519	0.000	0.000
	1984	0.641	0.000	0.000
	1985	0.653	0.000	0.000
Honey price, $PHFD$	1982	0.265	0.266	0.265
(equation 12.0)	1983	0.244	0.255	0.246
	1984	0.216	0.241	0.216
	1985	0.198	0.240	0.207
Import demand, IHM	1982	0.396	0.331	0.395
(equation 13.0)	1983	0.468	0.356	0.443
	1984	0.543	0.348	0.473
	1985	0.578	0.337	0.494
Wax price, $PWXD$	1982	0.772	0.779	0.780
(equation 14.0)	1983	0.605	0.632	0.605
	1984	0.563	0.620	0.603
	1985	0.484	0.568	0.484
Honey marketed, $QDHMM$	1982	0.568	0.853	−0.586
(equation 16.0)	1983	0.435	0.878	−0.437
	1984	0.138	0.804	−0.253
	1985	0.082	0.836	−0.096
Honey processing price, $PHRDF$	1982	0.470	0.464	0.472
(equation 17.0)	1983	0.449	0.451	0.449
	1984	0.421	0.434	0.434
	1985	0.403	0.433	0.417

Table 5. Continued

	Year	Support	No Support (Modified Adaptive Expectations)	No Support (Rational Expectations)
Beekeeper revenue (million $)	1982	83.8	80.3	80.0
	1983	74.3	72.7	67.5
	1984	63.9	63.1	52.8
	1985	57.8	62.9	47.9
Government payments (million $)	1982	27.4	0.0	0.0
	1983	48.0	0.0	0.0
	1984	90.2	0.0	0.0
	1985	80.8	0.0	0.0

References

Antonovitz, F., and R. Green. "Alternative Estimates of Fed Beef Supply Response to Risk." *American Journal of Agricultural Economics* 72 (1990):475–87.

Aradhyula, S. V., and M. T. Holt. "Risk Behavior and Rational Expectations in the U.S. Broiler Industry." *American Journal of Agricultural Economics* 71(1989):892–902.

Askari, H., and J. T. Cummings. "Estimating Agricultural Supply Response with the Nerlove Model: A Survey." *International Economics Review* 18(1977):257–92.

Atkinson, A. C. "A Method for Discriminating Between Models." *Journal of the Royal Statistical Society* Series B. 32 (1970):323–53.

Cumby, R. E., J. Huizinga, and M. Obstfeld. "Two-Step Two-Stage Least Squares Estimation in Models with Rational Expectations." *Journal of Econometrics* 21(1983): 333–35.

Fair, R. C., and J. B. Taylor. "Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models." *Econometrica* 51(1983):1169–85.

Fisher, B. S. "Rational Expectations in Agricultural Economics Research and Policy Analysis." *American Journal of Agricultural Economics* 64(1982):260–65.

Goodwin, T. H., and S. M. Sheffrin. "Testing the Rational Expectations Hypothesis in an Agricultural Market." *Review of Economics and Statistics* 64(1982):658–67.

Hoff, F. L., and J. K. Phillips. *Honey Background for 1990 Farm Legislation.* CED Staff Rep. no. AGES 89-43. U.S. Department of Agriculture, Economic Research Service, Washington, DC, 1989.

Labys, W. C. *Dynamic Commodity Models: Specification, Estimation and Simulation.* Lexington, KY: D.C. Heath and Company, 1973.

Lipton, D., J. Poterba, J. Sachs, and L. Summers. "Multiple Shooting in Rational Expectations Models." *Econometrica* 50(1982):1329–33.

McCallum, B. T. "Rational Expectations and the Natural Rate Hypothesis: Some Consistent Estimates." *Econometrica* 44(1976):43–52.

Muth, J. F. "Rational Expectations and the Theory of Price Movements." *Econometrica* 29 (1961):315–35.

Nerlove, M. *The Dynamics of Supply: Estimation of Farmer's Response to Price.* Baltimore: John Hopkins Press, 1958.

Newey, W. K., and K. D. West. *A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix.* Technical Working Paper no. 55. National Bureau of Economic Research, Cambridge, April 1986.

Pesaran, M. H. "On the General Problem of Model Selection." *Review of Economic Studies* 41(1974):153–71.

Pesaran, M. H., and A. S. Deaton. "Testing Non-Nested Nonlinear Regression Models." *Econometrica* 46(1978): 677–94.

Shideed, K. H., and F. C. White. "Alternative Forms of Price Expectations in Supply Analysis for U.S. Corn and Soybean Acreage." *Western Journal of Agricultural Economics* 14(1989):281–92.

Shideed, K. H., S. J. Brannen, and R. S. Glover. *Econometric Estimation of Soybean Supply Response under the Rational-Expectations Hypothesis.* Research Bulletin 352. Georgia Agricultural Experiment Stations, University of Georgia, Athens, December 1986.

Shonkwiler, J. S. "An Empirical Comparison of Agricultural Supply Response Mechanisms." *Applied Economics* 14(1982):183–94.

Shonkwiler, J. S., and R. D. Emerson. "Imports and the Supply of Winter Tomatoes: An Application of Rational Expectations." *American Journal of Agricultural Economics* 64(1982):634–41.

Tegene, A., W. E. Huffman, and J. A. Miranowski. "Dynamic Corn Supply Functions: A Model with Explicit Optimization." *American Journal of Agricultural Economics* 70(1988):103–11.

Wallis, K. F. "Econometric Implications of the Rational Expectations Hypothesis." *Econometrica* 48(1980):49–73.

Willett, L. S., and B. C. French. "An Econometric Model of the U.S. Beekeeping Industry." *American Journal of Agricultural Economics* 73(1991):40–54.

Zanias, G. P. "Adjustment Costs and Rational Expectations: An Application to a Tobacco Export Model." *American Journal of Agricultural Economics* 69(1987):22–29.