# Estimation of Imperfect Competition in Food Marketing: A Dynamic Analysis of the German Banana Market

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Several studies have estimated the welfare effects of recent changes in the European Union's common policy on banana imports, based upon the assumption that the market is perfectly competitive. However, if the market is imperfectly competitive, predictions about changes in banana policy may be inaccurate. The objective of this paper is to estimate the degree of market imperfection in the German market for banana imports using dynamic methods. The hypothesis that this market is perfectly competitive is rejected, and, in addition, the degree of market imperfection is estimated to be higher using a dynamic model compared to previous static estimates.

A key feature of much of the research in industrial organization over the past decade has been the application of non-cooperative game-theoretic methods to the analysis of imperfectly competitive markets (see Tirole, 1989). While the use of the Nash equilibrium to solve static one-period games has focused attention on the stability of oligopolistic outcomes such as Cournot-Nash, perhaps the most important advance made in the field has been the ability to analyze multi-period games that have oligopolistic equilibria. In particular, it has been shown that non-cooperative collusive equilibria can be obtained in repeated games (see Fudenberg and Tirole, 1989).

Parallel to these theoretical developments has been the evolution of the so-called "new empirical industrial organization" (NEIO). Research under the rubric of the NEIO uses structural econometric models to estimate market power in a given industry (Bresnahan and Schmalensee, 1987). Most NEIO studies have focused on domestic markets, and, moreover, estimate a market power parameter within a static framework (see Bresnahan, 1989; Perloff, 1992). Given the predictions of repeated game analysis, this procedure may be inappropriate if firms interact over several time periods. In addition, a dynamic framework is appropriate where there are substantial adjustment costs in changing production from one period to another (Karp and Perloff, 1993a).

In this paper, the degree of non-competitiveness in the German market for banana imports is estimated using a linear-quadratic dynamic game model, originally developed by Karp and Perloff (1989, 1993a, 1993b). A dynamic conjectural variations parameter is estimated, where the conjectural variations parameter nests the well-known market structures of perfect competition, Cournot-Nash and collusion. The methodology used in the current paper contrasts with earlier work by Deodhar and Sheldon (1995) which used a version of the static model developed by Bresnahan (1982) to generate an industry-wide, average parameter of market power in the German banana import sector.

The German market for banana imports was chosen for this study for three reasons. First, three multinational firms dominate the market (United Brands, Standard Fruit and Noboa) accounting for about 72 percent of the market (McCorriston and Sheldon, 1996). This apparently oligopolistic market structure derives largely from the existence of economies of scale in refrigerated shipping and distribution (Read, 1994). Second, adjustment costs in the production and export of bananas seem important as there is a gestation period of about a year and a quarter between the previous and current harvest. Third, the German banana import market has recently been subject to the implementation of import quotas as a part of

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changes in the European Union's (EU) banana import regime (Read, 1994). While existing studies of the impact of this regime assume perfect competition (Borrell and Yang, 1990, 1992; Borrell, 1994), recent analysis of the effects of trade policy in the presence of oligopoly (Helpman and Krugman, 1989) suggests that there is a premium on verifying empirically whether or not the banana export market is imperfectly competitive.

The paper is organized as follows. The linear-quadratic dynamic model used is described in Section 2. Essentially, this description involves the estimation of a demand function for banana imports in Germany, and a Markov equation that captures the strategic interaction among firms, based either on open-loop or feedback strategies. The parameters of these equations are then used in the solution to a dynamic programming problem in order to derive a dynamic conjectural variations parameter. The data used to estimate the above parameters and the results of the econometric analysis are reported and discussed in Section 3. Implications of the analysis are given in Section 4.

## A Linear-Quadratic Dynamic Game

In the present paper, the degree of market power enjoyed by the top three firms in the German market for banana imports is evaluated by estimating a dynamic conjectural variations parameter (Riordan, 1985) in the context of a linear-quadratic dynamic model. The term linear-quadratic comes from optimal control theory, and refers to a problem where the objective function is quadratic and the constraints are linear. The linear-quadratic approach has frequently been used in theoretical models of oligopoly (Fershtman and Kamien, 1987; Reynolds, 1987; Dockner, 1992; and Karp and Perloff, 1993a), and has been used in recent empirical work by Karp and Perloff (1989; 1993b). A particular advantage to using this approach is that closed-form solutions can be found for the equilibria of differential games, and, hence, it is possible to solve analytically for the conjectural variations parameter (Dockner, 1992; Karp and Perloff, 1993c). Tractable numerical solutions to non-linear problems are the subject of current research.

When modeling oligopolistic markets as dynamic games, two important equilibrium concepts are commonly used: *open-loop* and *feedback* Nash equilibrium. In an open-loop equilibrium, controls (i.e. moves made by a firm that constitute its strategy), are a function of time and the initial state. Since moves are independent of the current state of the system, and a firm is committed to a preannounced plan not anticipating any response, this equilibrium is not subgame perfect. A subgame perfect equilibrium is one where there is a Nash equilibrium for the whole game, and the firms' strategies are a Nash equilibrium for every sub-period within the game. Fixing strategies at the start of a game would clearly not be subgame perfect, if a firm subsequently wanted to change that strategy in response to other firms' strategies. In this sense, the open-loop equilibrium is the dynamic analog of the static Nash equilibrium where firms assume the output choices of opponents as given.

In contrast, in a feedback equilibrium, players design their optimal policies as decision rules dependent on the current state of the game. Since current state variables summarize the latest available information about the system, and since firms take the mechanism for determining future behavior as given, feedback strategies can be referred to as Markov strategies and a feedback equilibrium can be considered a subgame perfect equilibrium. The Markov equation is given as $q_t = Gq_{t-1}$, which depicts the linear decision rules for the firms, where $q_t$ is the output vector of firms at time $t$. It should be noted at this point that the adjustment paths for the open-loop and feedback equilibria are the same for the limiting cases of perfect competition and collusion with symmetric firms (see Karp and Perloff, 1993a). Another advantage of using the linear-quadratic approach is that open-loop and feedback strategies can easily be easily compared.

Given the open-loop strategy, and three symmetric firms in the German banana market, the objective (profit) function of an individual firm over an infinite time-horizon is assumed to take the following form:

**(1)**

$$\sum_{t=1}^{\infty}\beta^{t-1}\left[(P_t - \theta_i - 0.5\phi_i q_{it})q_{it} - (\omega_i + 0.5\delta_i u_{it})u_{it}\right]$$

where $P_t$ is the German retail price of bananas in period $t$, $q_{it}$ is the quantity of bananas exported to Germany by the $i^{th}$ firm in period $t$, $u_{it}$ is the change in exports of firm $i$ from period $t\text{-}1$ to period $t$, and $\beta$ is the discount factor. The term $(\theta_i + 0.5\phi_i q_{it})q_{it}$ represents the quadratic production cost, and $(\omega_i + 0.5\delta_i u_{it})\, u_{it}$ represents quadratic production adjustment costs. The inverse demand function $P_t$ is assumed to take a linear form:

(2) $$P_t = a - b\sum_{i-1}^{n} q_{it} = a - bQ_t$$

Converting the objective function (1) into matrix form, and deriving the first-order-condition restrictions, gives the following matrix equation[1]:

(3) $$K_i V_i = [G^{-1}(I - G)(I - \beta G)]' e_i \delta_i$$

$K_i$ is defined as $b(ee'_i + e_i e') + \phi_i e_i e'$, where $b$ and $\phi_i$ are the demand slope and production adjustment parameters respectively, $e_i$ is a column vector with 1 in the $i^{th}$ row and zeros elsewhere, and $e$ is a column vector with 1 in each row. $V_i$ is a three into one column vector with one in the $i^{th}$ row and $V_{ij}$ and $V_{ik}$ in the remaining rows, where $V_{ij}$ is defined as $du_{jt}/du_{it}$, and similarly $V_{ik}$. $G$ is a 3x3 matrix that establishes the relation between $q_t$ and $q_{t-1}$.

In deriving equation (3), no symmetry assumptions are made, however, for analytical tractability, symmetry is introduced at this stage. Specifically, it is asumed that $V_{ij}=V \forall i, j$; $\delta_i=\delta \forall i$; and $G$ is symmetric such that elements $G_{ij}=g_1 \forall i=j$; $G_{ij}=g_2 \forall i\neq j$. The dynamic conjectural variations parameter $V$ ranges from -1/(n-1) for the case of perfect competition, where n is the number of firms, through 0 for Cournot-Nash, to 1 for perfect collusion, the same range as in a static framework. It should be noted that treating firms as having similar conjectures is a relatively restrictive assumption, implying that firms have similar cost structures. Unfortunately, it is not possible computationally to derive separate estimates for the elements of $V_i$, the number of unknown parameters exceeding the number of equations.

As mentioned earlier, the open-loop strategy concept is naive, and, therefore, it is necessary to incorporate a subgame perfect feedback strategy. The value function method of dynamic programming is used to set up the dynamic objective function for this kind of firm behavior. If the value of the present and discounted future profits of firm $i$ can be expressed as $J_i(q_{t-1}, V_i)$, where $V_i$ is defined as above, then firm $i$'s dynamic programming profit maximization problem can be written as:

(4)
$$J_i(q_{t-1}, V_i) = \max[(P_t - \theta_i - 0.5\phi_i q_{it})q_{it} - (\omega_i + 0.5\delta_i u_{it})u_{it} + \beta J_i(q_t, V_i)].$$

Converting this objective function into matrix form, and deriving the first-order-condition restrictions gives the following matrix equation:

(5) $$[K_i + \beta W_i + (e_i e'_i + \beta X_i)\delta_i]' V_i = [G']^{-1} e_i \delta_i \equiv y_i \delta_i.$$

Again, no symmetry assumptions are required for deriving this condition, however, the symmetry requirements used in the open-loop case are introduced here too.

Matrix equations (3) and (5) have two unknowns, the conjectural variations parameter $V$ and the cost of adjustment parameter $\delta$. The rest of the matrices in these equations are expressed in terms of the slope parameter of the inverse demand function, $b$, and a lagged coefficient matrix $G$ from the Markov equation. Specifically, matrix $K_i$ is expressed in terms of $b$, matrix $X_i$ is expressed in terms of $G$, and matrix $W_i$ is expressed in terms of both $b$ and $G$. Therefore, it is necessary to estimate the matrix $G$, and recover the parameter $b$ in order to solve matrix equations (3) and (5) for $V$ and $\delta$. In both cases, $V$ is a function of $G$ alone, and $\delta$ is a function of both $b$ and $G$. For the open-loop case, a unique solution exists for $V$; however, for the feedback case, there are two solutions that emerge from solving a quadratic equation in $V$. One solution is close to the

[1] The derivations of these equations and their solutions are available from the authors. They are also available in Karp and Perloff (1993c).

open-loop value, and the other is infeasible (see the Appendix for the exact derivations of $V$ and $\delta$). The procedure followed in estimating $b$ and $G$ is outlined in the next section.

**Empirical Analysis**

*Estimation of Demand Equation*

In order to estimate the parameter $b$, a linear demand function was specified initially for the German banana market as follows:

$$Q_t = \alpha_0 + \alpha_1 P_t + \alpha_2 O_t + \alpha_3 Y_t + \alpha_4 Z_t + \alpha_5 T + \alpha_6 TT + \varepsilon_t \quad (6)$$

$Q_t$ represents the total quantity of bananas imported annually into Germany over the period 1970-1992 and $P_t$ represents the real retail price of bananas. $O_t$ is the real retail price of oranges, a substitute fruit for bananas; $Y_t$ is real per capita GNP for Germany; $Z_t$ is the German population aged 65-and-above; $T$ and $TT$ are trend variables; and $\varepsilon_t$ is the error term. The demand parameter $b = 1/\alpha_1$.

The parameter estimates of the own-price ($P_t$), cross-price ($O_t$), and income variables ($Y_t$) are expected to have negative, positive, and positive signs respectively, while the population variable ($Z_t$) is expected to have a positive parameter. The inclusion of the latter variable is justified on the grounds that, while the total population of Germany was constant over the time period under consideration, the population has been aging, and, therefore, population in the age cohort 65-and-above is growing. A report by the European Commission (1976) states that bananas are an important part of the diet of the sick and elderly. The trend terms $T$ and $TT$ are included due to the plot of the dependent variable $Q_t$ exhibiting the shape of an inverted parabola, hence, it is expected that $T$ will have a negative parameter, and $TT$ a positive parameter.

Annual data on aggregate quantities of bananas imported into Germany ($Q_t$), retail prices ($P_t$), and import prices $(M_t)$[2] were collected for the period 1970-1992 from the Food and Agriculture Organization (FAO) publications: World Banana Economy (1983) and Banana Statistics (1992). Data on the retail price of oranges ($O_t$) were collected from the FAO Production Yearbook, and German income data were collected from the International Monetary Fund (IMF) publication: International Financial Statistics (1992, 1994). The demographic variable ($Z_t$) was collected from Warnes (1993), and the International Labour Office (ILO) publication: From Pyramid to Pillar (1989).[3] The German consumer price index used for deflating the nominal variables, with a base year of 1985, was collected from International Financial Statistics (1992, 1994).

Ordinary Least Squares (OLS), based on Shazam (Version 7.0, 1993), was used to estimate (6). The results of the final estimation, from which the estimate of $b$ was chosen, are presented in Table 1, indicating that the R-square between observed and predicted is 0.95. The parameter estimate for $P_t$ is -0.33 which is significant at the 1 percent level. The parameter for the population variable $Z_t$ has the expected sign and is significant at the 5 percent level. The parameters on the trend variables $T$ and $TT$ also take their expected signs and are significant at the 1 percent level. In terms of diagnostics, the Durbin-Watson ratio is 1.53441, with a p-value of 0.021401, which indicates that, at the 2.1 percent significance level, the null hypothesis of no autocorrelation cannot be rejected. As a further test for the existence of autocorrelation in the residuals, the Box-Pierce statistic was calculated.[4] The value of 8.895 with 6 degrees of freedom is less than the critical value of $\chi^2 = 10.64$ at the 10 percent level of significance, indicating that the residuals are drawn

[2] Import price refers to the f.o.b. price charged by importers to wholesalers at the port of Hamburg.

[3] Total population figures were available for every year; however, population for age 65-and-above, was reported as a percentage of total population every five years. Other values were interpolated.

[4] The Box-Pierce statistic is defined as $B = T \sum_{j=1}^{P} \hat{p}_j^2$ where $T$ is the sample size, $\hat{p}_j$ are the estimated autocorrelation coefficients from the autocorrelation function, $j$ is a given lag and $P$ the total number of lags. $B$ is distributed approximately as $\chi^2$ with $P$ degrees of freedom (see Pindyck and Rubinfeld (1981).

from a white-noise series.

It should be noted at this point that initial estimation of (6) indicated that neither the parameter for the price of oranges $O_t$ nor that for the income variable $Y_t$ were statistically significant.[5] As a result these explanatory variables were dropped from the final estimation of (6). The statistical insignificance of these variables is perhaps not surprising. As reported by the World Bank (1985), the cross-price elasticity of bananas with other fruits is very low. It is reported as 0 in Germany, which is similar to estimates for other developed countries, e.g. Huang (1993) reports a value of 0.08 for the cross price elasticity between bananas and oranges in the United States. Thus, the choice of bananas in consumption is a matter of customer preference, and other fruits are not accepted as ready substitutes. The World Bank (1985) also reports that banana consumption is only responsive to income in countries where per capita GNP is less than $1500. In countries like Germany, with a very high per capita income, banana consumption has reached saturation level with respect to income variations.

**Table 1. Estimation of the Demand Function.**

$$Q_t = \underset{(1.48)}{789} - \underset{(-5.09)}{0.33P_t^{**}} + \underset{(1.79)}{98Z_t^{*}} - \underset{(-11.4)}{80T^{**}} + \underset{(14.0)}{4.3TT^{**}}$$

R-square between observed and predicted = 0.95
Durbin-Watson statistic = 1.53441
Durbin-Watson p-value = 0.021401
Box-Pierce statistic = 8.895

Note: Figures in parenthesis refer to t ratios
** Significant at the 1 percent level
* Significant at the 5 percent level

*Estimation of Markov Equation*

As well as estimating $b$, the dynamic model also requires estimation of a system of Markov equations, one for each firm, where the banana exports of the three multinational firms $q_{it}$, $i$=1,.,3, are regressed on the lagged values of their own exports $q_{it-1}$ to Germany and the lagged values of exports of the other multinational firms $q_{jt-1}$, $i \neq j$. Quantities of bananas exported to Germany by the individual multinational firms were not available directly; however, market shares of multinational firms in the German banana market were available for the years 1973 to 1989 and were applied to total German imports to give shares of the market at the firm level.[6] These market shares were collected from International Fruit World (1988), and the FAO publications, World Banana Economy (1983, 1986).

As noted earlier, matrix $G$ gives a relationship between $q_t$ and $q_{t-1}$ given by $q_t = Gq_{t-1}$. To recover matrix $G$, this relationship is estimated using Zellner's (1962) seemingly unrelated equations (SURE) method. The model requires restricting the elements of the $G$ matrix such that the own lagged coefficients ($g_1$) are the same for the three firms, and lagged coefficients for the other firms ($g_2$) are the same for the three firms. The F statistic for imposing these restrictions is 1.6, and the critical value for testing the restrictions, F(7,36) is 2.3 at the 5 percent significance level. Therefore, the restrictions cannot be rejected. Since the restrictions are not rejected, they are imposed, and the regression equations are re-estimated, the results being presented in Table 2.

*Calculation of V and δ and Hypothesis Testing*

Using the estimates of $b$ and $G$, the conjectural variations parameter $V$ and the cost of adjustment parameter $\delta$ were calculated for the open-loop and feedback models, the results being shown in Table 3. The subscripts of $V$ and $\delta$, $o$ and $f$, refer to the open-loop and feedback strategies respectively, and the superscript $c$ refers to classical estimates, named as such to distinguish them from the bootstrap estimates that are discussed subsequently. Standard errors are

[5] The estimated equation including $O_t$ and $Y_t$ was as follows:

$$Q_t = \underset{(-0.15)}{-140} - \underset{(-3.4)}{0.28P_t} + \underset{(0.33)}{0.03O_t} + \underset{(1.23)}{36.4Y_t} + \underset{(1.76)}{94.04Z_t} - \underset{(-6.19)}{98.03T} + \underset{(9.5)}{4.13TT}$$

R-square between observed and predicted = 0.96, Durbin-Watson = 1.45.
Exclusion of $T$ and $TT$ from this equation does not improve the explanatory power of $O_t$ and $Y_t$.

[6] It should be noted that the years 1990-1992 were characterized by an unusual export trend generated by expectations about the EU's common import policy for bananas. By the end of 1992, the EU was deliberating on setting common quotas and tariffs on banana imports. In light of this, the banana multinationals started exporting large amounts of bananas to the EU, expecting that the level of quotas would be influenced by the amounts imported in recent years. Thus, recent exports of bananas do not reflect strategic interaction of firms, but the result of an anticipated exogenous policy change.

**Table 2. Banana Export Adjustment (Markov) Equation.**

| | Bonita: $q_{1t}$ | Chiquita: $q_{2t}$ | Dole: $q_{3t}$ |
|---|---|---|---|
| Time trend | 2.43 | 3.85 | 2.36 |
| | (6.10) | (5.20) | (4.95) |
| Own lagged exports ($g_1$) | 0.85376 | 0.85376 | 0.85376 |
| | (22.97) | (22.97) | (22.97) |
| Lagged exports of other firms ($g_2$) | -0.03485 | -0.03485 | -0.03485 |
| | (-3.22) | (-3.22) | (-3.22) |
| R-square | 0.97 | 0.83 | 0.51 |
| Durbin's h | -1.53 | 1.15 | 1.47 |

Note: Figures in parenthesis refer to t ratios

**Table 3. Classical Estimates of Dynamic Model.**

| $V_o^c$ | $\delta_o^c$ | $V_f^c$ | $\delta_f^c$ |
|---|---|---|---|
| 0.08 | 0.187 | 0.20 | 0.191 |
| (0.36) | -- | (0.33) | -- |

| Hypothesis | Test Statistic | Remark |
|---|---|---|
| $H_0: V_o^c = -0.5, H_1: V_o^c > -0.5$ | 1.60 | Cannot reject $H_0$ at 5% or 1%. |
| $H_0: V_o^c = 0, H_1: V_o^c \neq 0$ | 0.22 | Cannot reject $H_0$ at any level. |
| $H_0: V_o^c = 1, H_1: V_o^c < 1$ | 2.50 | Reject $H_0$ at any level. |
| $H_0: V_f^c = -0.5, H_1: V_f^c > -0.5$ | 2.13 | Reject $H_0$ at 5% & 2.5%. |
| $H_0: V_f^c = 0, H_1: V_f^c \neq 0$ | 0.60 | Cannot reject $H_0$ at any level. |
| $H_0: V_f^c = 1, H_1: V_f^c < 1$ | 2.42 | Reject $H_0$ at 5% and 1%. |

Note: Figures in parenthesis are standard errors

**Table 4. Bootstrapping* of Dynamic Model.**

| | | Open-loop | Feedback |
|---|---|---|---|
| Mean values of $V$ and $\delta$ | | $V_o^B$=0.06, $\delta_o^B$=0.22 | $V_f^B$=0.17, $\delta_f^B$=0.23 |
| Standard error | | 0.33, 0.13 | 0.30, 0.13 |
| Values | Unstable | 0.2% | 0.2% |
| rejected | $\delta < 0$ | 2.8% | 0.0% |
| because | $V < -0.5$ | 2.8% | 2.8% |
| | $V > 1$ | 8.7% | 8.7% |

*1000 iterations performed of δ are also calculated based on bootstrapping.

**Table 5. Hypothesis Testing for Bootstrapped $V$ and δ.**

| Hypothesis | t-ratio | Remark |
|---|---|---|
| $H_0: V_o^B = -0.5, H_1: V_o^B > -0.5$ | 1.70 | Reject $H_0$ at 5%. |
| $H_0: V_o^B = 0, H_1: V_o^B \neq 0$ | 0.17 | Cannot reject $H_0$. |
| $H_0: V_o^B = 1, H_1: V_o^B < 1$ | -2.90 | Reject $H_0$ at any level. |
| $H_0: \delta_o^B = 0, H_1: \delta_o^B > 0$ | 1.74 | Reject $H_0$ at 5%. |
| $H_0: V_f^B = -0.5, H_1: V_f^B > -0.5$ | 2.20 | Reject $H_0$ at 5% and 2.5%. |
| $H_0: V_f^B = 0, H_1: V_f^B \neq 0$ | 0.56 | Cannot reject $H_0$. |
| $H_0: V_f^B = 1, H_1: V_f^B < 1$ | -2.70 | Reject $H_0$ at all levels. |
| $H_0 \delta_f^B = 0, H_1: \delta_f^B > 0$ | 1.76 | Reject $H_0$ at 5%. |

calculated for $V$ using the Taylor expansion method.[7] The results show that both values of $V$ are positive, however, the hypothesis of Cournot-Nash behavior cannot be rejected. The hypothesis of collusive behavior is rejected for both types of firm behavior, and that of perfect competition is rejected only in the case of feedback strategies. Interestingly, the estimate of $V$ for the feedback case (0.20) is larger than both the open-loop value (0.08) and, also, the equivalent static value derived by Deodhar and Sheldon (1995).

As an alternative to the classical estimates derived from the Taylor expansion, a bootstrap procedure can also be utilized (Efron, 1979).[8] Bootstrapping was performed by resampling the original data with replacement (Freedman and Peters, 1984). In the present context, this involves bootstrapping the Markov equation, and generating numerous values of $g_1$ and $g_2$. These values, in turn, are used to calculate $V$ and δ, along with their mean values and standard errors. The results of this procedure are given in Table 4, where superscript $B$ refers to the bootstrap estimate. Resampling and regressing the data 1000 times with replacement, the inequality restrictions on $g_1$ and $g_2$, and $V$ and δ are imposed, and constrained estimates of $V$ and δ are derived. While the estimates of $V$ are a little lower than in the classical case, their relative position is maintained. The standard errors of $V$ show a similar pattern. Also, the values of δ are higher than in the classical case, but their relative position is maintained. The standard errors of δ are also calculated based on bootstrapping the Markov equations that generate multiple values of $g_1$ and $g_2$.

Finally, the results of hypothesis tests conducted for the bootstrap estimates of $V$ and δ are presented in Table 5. In the classical case, the hypothesis of perfect competition was not rejected in the case of open-loop behavior, but it was rejected for feedback behavior. In the case of the bootstrap estimates, perfect competition is rejected under both open-loop and feedback behavior. The hypothesis of collusive behavior is also rejected in both cases. Only the hypothesis of Cournot-Nash behavior is not rejected. Again the feedback estimate of $V$ (0.17) is greater than both the open-loop estimate (0.06) and, also, the corresponding static value reported by Deodhar and Sheldon (1995). For both behavioral assumptions, the hypothesis of δ=0 was rejected. This shows that, even though the absolute value of the parameter is small, it is statistically significant, and the costs of adjustment in banana production are important.

## Implications

This paper has focused on estimating the degree of market imperfection in the German

[7] We benefitted from an e-mail discussion with Professor Perloff on how to employ the Taylor expansion method to calculate the standard error of V, and he kindly made available a copy of his original program.

[8] Bootstrapping is a computer intensive nonparametric approach to statistical inference based on data resampling. A good treatment of it is found in Judge *et al.* (1988).

market for banana exports. Using a linear-quadratic dynamic oligopoly model, the degree of market imperfection was estimated. Using a bootstrapping procedure, the maintained hypothesis of perfect competition is rejected, however, the hypothesis that firms operate in a Cournot-Nash fashion cannot be rejected. In fact, the classical and bootstrap estimates of the dynamic feedback conjectural variations parameter (0.20 and 0.17) are larger than the corresponding static value derived in a previous study of the German banana import market by Deodhar and Sheldon (1995). Further, the estimates of the adjustment parameter $\delta$ in the dynamic model are significantly different from zero, suggesting that a dynamic model is more appropriate for analyzing the market for a commodity such as bananas.

These results have important implications for analysis of the welfare effects of the implementation of the common EU banana import regime. In the case of Germany, an effective import quota has been implemented in that market (Read, 1994). When evaluating the impact of a quota, it is crucial to estimate how noncompetitive the market was under free trade. Import quotas can affect the strategic behavior of firms in such a way as to make its impact non-equivalent to that of a tariff in terms of domestic price effects (see McCorriston and Sheldon, 1996). Most economic studies, however, of the implementation of a common EU banana import regime have assumed that the market is perfectly competitive in structure (see Borrell and Yang, 1990, 1992; Borrell, 1994). Our results show that this assumption is questionable.

The welfare effects of implementing trade instruments such as quotas are likely to be highly sensitive to the underlying game being played by firms. For example, Krishna (1989) predicts that firms adjust from Bertrand-Nash to more collusive behavior after implementation of a quota. Hwang and Mai (1988) have also shown in a conjectural variations model that quantitative restraints such as quotas and voluntary export restraints can cause either pro- or anti-competitive effects, or neither, depending on the initial values of the firms' conjectures, i.e. how (un)competitive the market was prior to the imposition of the quota. In turn, this either exacerbates or dampens the effect of a quantitative restriction on domestic prices compared to the effects of a tariff.

The results presented in this paper suggest that raising non-tariff barriers to the German market has probably not altered the strategic behavior of firms by very much as firms are already behaving oligopolistically, and, therefore, the increase in banana prices in Germany is what would have likely occurred under an equivalent tariff. Our study also shows that the estimation of the degree of market imperfection depends on the intertemporal strategic interaction among market participants, and, therefore, dynamic models need to be employed for the estimation of market power. It also reinforces the importance of viewing firms as being involved in repeated rather than static games.

**Appendix:**

*Solving the open-loop model for V and δ*

The first-order-condition restriction from (3) is given as:

$$K_i V_i = [G^{-1}(I-G)(I-\beta G]' e_i \delta_i$$

Imposing the symmetry conditions, and expanding the matrices, (assuming n=3):

$$\begin{bmatrix} 2b & b & b \\ b & 0 & 0 \\ b & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ V \\ V \end{bmatrix} = Z_{(3x3)} \begin{bmatrix} \delta \\ 0 \\ 0 \end{bmatrix}$$

where $Z$ is a symmetric matrix, and $\phi_i$ is assumed to be 0, which implies that marginal cost is constant. The matrices are multiplied to obtain two equations:

$$b = Z_{2,1}\delta$$

$$2b + 2bV = Z_{1,1}\delta$$

$$\therefore \quad \delta = \frac{b}{Z_{2,1}}, \text{ and } V = \frac{Z_{1,1}}{2\,Z_{2,1}} - 1$$

*Solving the feedback model for V and δ*

The first-order-condition restriction from (5) is:

$$[K_i + \beta W_i + (e_i e'_i + \beta X_i)\delta_i]' V_i + G'^{-1} e_i \delta_i \equiv y_i \delta_i$$

Under the assumption of symmetry, the rank of the matrices in the above equations is two, and we need to look only at the first two equations. Define matrix $A^i$ and $B^i$ so that $Ba^i \equiv K_i + \beta W_i$ and $B^i \equiv e_i e_i' + \beta X_i$. The $i^{th}$ and $j^{th}$ equation is:

$$b\left(A_{ii} + V \sum_{j \neq i} A_{ij}\right) + \left(B_{ii} + V \sum_{j \neq i} B_{ij}\right)\delta = y_{ii}\delta$$

and

$$b\left(A_{ki} + V \sum_{j \neq i} A_{kj}\right) + \left(B_{ki} + V \sum_{j \neq i} B_{kj}\right)\delta = y_{ik}\delta$$

where $A_{ij}$, $B_{ij}$ and $y_{ii}$ are elements of $A^i$, $B^i$ and $y_i$. Solving the second equation gives δ as a linear function of $b$ and a nonlinear function of $V$. Substituting the value of δ into the first equation gives a quadratic in $V$ that is independent of $b$. Of the two roots of $V$, one is closer to the open-loop solution, and the other falls outside the theoretical range. Therefore, the feasible root is picked. Here, $V$ is a function of β and $G$, and δ is a function of $b$, β and $G$.

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