The Supply Response for Rubber in Sri Lanka

A Preliminary Analysis

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Abstract

Study of supply response for perennial crops has frequently been limited by lack of data: in many instances data are available only on output, producer prices, and area under cultivation. This has led many investigators to concentrate on the estimation of a "reduced-form" equation that may fail to capture important structural features of the determination of the supply response of these crops. Our study is based on new extensive time series for rubber in Sri Lanka covering total output, producer prices, new plantings, replantings, wage rates, area under cultivation (disaggregated by region, type of planting, size of holding, and age), as well as many other variables. In addition, we have a survey of 49 rubber estates in which data have been collected on yields, type and age of clone, stand densities, and many other variables. These panel data cover a 10 year period, 1970-79. This paper reports some preliminary analysis of the Sri Lankan data designed to test the adequacy of Dowling's analysis of supply response for rubber in Thailand, based on a quite sophisticated reduced form supply function developed by Wickens and Greenfield for Brazilian coffee. Because the uprooting-replanting decision is central to understanding rubber supply response in Sri Lanka and because this particular structural feature is obscured in these reduced form formulations, they prove inadequate. Our model not only focuses on the uprooting-replanting decision but disaggregates the "reduced form" into several structural relationships. Essential use is made of the age distribution and age-yield profile data from the estate surveys at our disposal. This modest extension of the Wickens-Greenfield formulation performs significantly better in the Sri Lankan context, than a straightforward application of the model.

Extracto

El estudio de la reacción de la oferta de cultivos perennes frecuentemente se ha visto limitado por falta de datos: en muchos casos hay datos disponibles únicamente sobre la producción, los precios a los productores y la superficie cultivada. Esto ha llevado a muchos investigadores a concentrar la atención en el cálculo de una ecuación de "forma reducida", que puede no captar características estructurales importantes para la determinación de la reacción de la oferta de estos cultivos. Nuestro estudio se basa en series cronológicas nuevas y amplias relativas al caucho en Sri Lanka, que comprenden la producción total, los precios a los productores, las nuevas plantaciones, las replantaciones, los salarios, la superficie cultivada (desagregada por región, tipo de plantación, tamaño de las explotaciones y edad de la plantación), así como muchas otras variables. Además, se ha realizado una encuesta de 49 plantaciones de caucho, en la cual se recopilaron datos sobre rendimientos, tipo y edad de los clonos, densidades de plantío y muchas otras variables. El conjunto de datos abarca un período de 10 años, de 1970 a 1979. En el presente documento aparece un análisis preliminar de los datos de Sri Lanka que tiene por finalidad poner a prueba la validez del análisis Dowling de la reacción de la oferta del caucho en Tailandia, basándose en una función-oferta de forma reducida bastante avanzada, desarrollada por Wickens y Greenfield para el café brasileño. Como la decisión de erradicar o replantar es de importancia fundamental para comprender la reacción de la oferta del caucho en Sri Lanka y debido a que esta característica estructural específica no se define netamente en estas formulaciones reducidas, las mismas resultan inapropiadas. Nuestro modelo

no sólo se centra en la decisión de erradicar o replantar sino que también desagrega la "forma reducida" en varias relaciones estructurales. Se utilizan fundamentalmente los datos sobre distribución por edad y el perfil de los rendimientos por edad obtenidos de las encuestas disponibles de las plantaciones. En el contexto de Sri Lanka, esta modesta ampliación de la formulación de Wickens-Greenfield proporciona resultados significativamente mejores que los de la aplicación directa del modelo.

Faute de données, il est difficile d'étudier l'évolution de l'offre de cultures pérennes : dans bien des cas, les statistiques disponibles ne portent que sur la production, les prix à la production, et les superficies cultivées. De ce fait, de nombreux chercheurs doivent se borner à formuler une équation de "forme réduite", qui ne tient pas toujours compte de certains éléments structurels importants pour déterminer l'évolution de l'offre de ces cultures. La présente étude se fonde sur de nouvelles séries chronologiques de grande ampleur concernant le caoutchouc à Sri Lanka; elles portent sur la production totale, les prix à la production, les nouvelles plantations, les replantations, l'échelle des salaires, les superficies cultivées (ventilées par région, type de plantation, taille d'exploitation et âge), ainsi que sur bien d'autres variables. La Banque mondiale dispose en outre d'une enquête sur 49 plantations de caoutchouc, qui contient des statistiques sur les rendements, le type et l'âge des clônes, la densité des peuplements, et de nombreuses autres variables. Celles-ci couvrent une période de 10 ans (1970-79). Le présent document comporte quelques analyses préliminaires des données concernant Sri Lanka, analyses visant à vérifier la justesse des travaux de Dowling sur l'évolution de l'offre de caoutchouc en Thaïlande, à partir d'une fonction d'offre de forme réduite, mais très élaborée, construite par Wickens et Greenfield pour le café du Brésil. Toutefois, les décisions relatives à l'arrachage et à la replantation sont d'une importance capitale pour déterminer l'évolution de l'offre de caoutchouc à Sri Lanka,

et comme les formulations simplifiées ne tiennent pas compte de cet élément structurel particulier, elles se révèlent inadéquates. Le modèle présenté dans ce document n'est pas seulement fondé sur les décisions d'arrachage et de replantation, mais il désagrège la "forme réduite" en diverses relations structurelles. Les données afférentes à la répartition par âge et aux profils de rendement correspondant à cette répartition, que contiennent les études de la Banque sur les plantations de caoutchouc, jouent un rôle très important dans le modèle. Dans le cas de Sri Lanka, cette modeste extension de la formulation Wickens-Greenfield permet d'obtenir des résultats sensiblement plus satisfaisants que l'application directe du modèle originel.

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1. Introduction

Study of supply response for perennial crops has frequently been limited by lack of data: in many instances, data are available only on output, producer prices, and area under cultivation. Occasionally such data are supplemented by information on the age distribution of the stock of trees, the proportion of the stock uprooted over time, new plantings, replantings, removals, labor and other inputs (principally fertilizer), and corresponding prices. Because of the data limitations, many investigations must inevitably rely on greatly simplified "reduced-form" equations that may fail to capture important structural features of the determination of the supply response of perennials. Moreover, technological progress generally takes the form of improvement of varieties or clones. With the result that, when additions are made to the stock of trees, significant increases in the yields of a given age-class are obtained over time. Thus, the new planting/replanting decisions and the age and clonal composition of the stock are crucial in understanding the supply response.

In Sri Lanka, it turns out that the replanting decisions are in fact of overwhelming importance in the determination of supply response. Moreover, such decisions are qualitatively different from new planting decisions in the case of rubber, or indeed of any perennial with a long gestation period. This contrasts rather sharply with the neoclassical view of the investment decision, in which investment for net additions to the capital stock and replacement investment are regarded as equivalent in terms of the derived demand for the stock of capital as a factor of production. The reason replacement demand is so different than demand for net additions in this

context is that old and still productive capital must be removed to replace new capital, which in turn cannot be expected to yield its flow of productive services for a considerable future period. Response to high current prices must, for example, take into account information affecting future prices as well as current prices. 1/ Moreover, expected changes in future technology affect the obsolescence of the current stock as well as the desirability of future investment.

Recently, extensive time series have become available for rubber in Sri Lanka covering total output, producer prices, new plantings, replantings, wage rates, area under cultivation (disaggregated by region, type of planting, size of holding and age), fertilizer prices and use, and monthly climatic conditions by growing district. In addition, the World Bank has undertaken a survey of forty-nine estates in which data have been collected on yields, type and age of clone, fertilizer application, tapping systems and intensities, stand densities, rainfall, elevation and soil type by field within estate, and on labor inputs. These panel data cover a ten-year period, 1970-79.

This paper reports some preliminary analyses of the Sri Lankan data, designed to test the adequacy of the most recent supply response study for rubber (Dowling, 1979) based on a relatively sophisticated reduced form supply function developed by Wickens and Greenfield (1973). Because this formulation proves inadequate to describe the main features of rubber supply response in Sri Lanka, we have extended the Wickens-Greenfield formulation in a way that makes better use of the age distribution and age-yield profile data at our disposal. Although this modest extension performs significantly better in the Sri Lankan context, it far from exhausts the potential of our data set for the analysis of the determinants of rubber supply response. Further analyses

making greater use of our data set are planned.

2. Recent Studies of Perennial Supply Response with Particular Reference to Rubber

a. An application of the Nerlove model by Grilli *et al.* (1981)

The formulation developed by Nerlove (1956) for the study of supply response for annual crops has been used with little or no modification for the study of perennials. An example is the study of rubber by *inter alios*, Grilli *et al*. (1979). Stripped to its essentials, the Nerlove model consists of three equations:

$$(1) \qquad A_t - A_{t-1} = \gamma(A^*_t - A_{t-1}),$$

$$(2) \qquad P^*_t - P^*_{t-1} = \beta(P_{t-1} - P^*_{t-1}),$$

$$(3) \qquad A^*_t = a_o + a_1 P^*_t + a_2 Z_t + u_t,$$

where A_t is the actual area under cultivation in period t; P_t is the actual (real) price of the crop per unit in t; A^*_t is the equilibrium, or area "desired" to be under cultivation in t; P^*_t is the "expected normal" (real) price in t for all subsequent future periods; Z_t represents a vector of all other observed and presumably exogenous factors; and u_t captures other unobserved or "latent" factors, affecting the area under cultivation in t. The parameters β and γ are, respectively, the coefficients of expectation and adjustment reflecting the responses of expectations to observed prices and of observed areas under cultivation to changes in equilibrium areas.

This model leads to a reduced-form equation of the form:

$$(4) \qquad A_t = \gamma\beta\alpha_o + \gamma\beta\alpha_1 P_{t-1} + \gamma\alpha_2 Z_t - \gamma(1-\beta)\alpha_2 Z_{t-1} + [(1-\gamma)+(1-\beta)]A_{t-1}$$

$$- (1-\beta)(1-\gamma)A_{t-2} + \gamma u_t - \gamma(1-\beta)u_{t-1}$$

It is possible to recover estimates of the structural parameters when variables such as Z are present in the equation. These variables determine the long-run equilibrium level, but are not "expectational." In practice a reduced form model is estimated directly from a Nerlove model--couched either in terms of area (A_t) or output (q_t)--without imposing any restrictions on the reduced-form parameters.

E.g., Grilli et al. (1981) fit the following linear model:

$$(5) \qquad q_t = \delta_o + \delta_1 q_{t-1} + \delta_2 P_t + \delta_3 t + u_t,$$

where q_t is output (in tons of natural rubber), P_t is the producer price received by producers there relative to the GNP deflator, and t is a time trend. The results for three main producing countries, Malaysia, Indonesia, Thailand, and the Rest of the World, are shown in Table 1. For Indonesia, a dummy variable (1 for 1963, 0 otherwise) and t^2 have been included as dependent variables. For the "rest of the world", rubber price is the price in Singapore deflated by the U.S. wholesale price index.

TABLE 1: Supply Elasticities for Natural Rubber Obtained by Grilli et al. (1981)

Country	Short-Run Supply Elasticity	Coefficient of Lagged Output
Malaysia	0.19	0.425
Indonesia	0.10	0.324
Thailand	0.24	0.379
Rest of the World	0.15	0.336

Comparison with the Nerlove reduced form when derived from a structure involving q_t (rather than A_t) reveals that either the adaptive expectation coefficient, β, or the partial adjustment coefficient, γ, must be one to eliminate q_{t-2} from the model if the latter is the underlying-maintained hypothesis. The long-run supply elasticities implied by the results are about double the short-run elasticities. The latter appear to be quite low--less than 0.25--in all cases.

As pointed out by Wickens and Greenfield (1973), as well as Grilli et al., this formulation fails to distinguish between the investment decision regarding the stock of trees and the harvesting decision. Consequently, the implications of the biological relationship between the age of the tree stock and its yield, as well as the "vintage" effects of improvements in varieties, are obscured. Short-run supply response, with a given stock of trees, cannot be disentangled from long-run responses involving adjustments in the size of the stock of trees and its age and varietal composition arising from past new planting, uprooting and replanting decisions. Thus, the interpretation of the results of Grilli et al. reported in Table 1, for either short- or long-run rubber supply response, is arguable.

b. Wickens and Greenfield (1973) on Coffee

Perhaps the most sophisticated model of perennial supply, yet published, is due to Wickens and Greenfield (hereafter WG) who develop a vintage model and estimate the supply response for Brazilian coffee. Also, their model has recently been applied to rubber in Thailand by Dowling (1979). While WG regard the preferred approach to be direct specification and estimation of the structural relationships in their model of perennial supply --namely, an investment function, a harvesting decision function, and a vintage production function--data limitations usually preclude this. Instead, the procedure adopted by both WG and Dowling is to specify the structural relationships and derive a reduced-form supply function that can be estimated directly from available data. It is possible, however, to draw inferences about the structural relations through the use of extraneous information on the age composition to determine the shape of the distributed lag response of supply to changes in relative prices. It is worth examining the model and results of WG in some detail as it is the point of departure for our approach. Also, Dowling bases his recent work on rubber on the WG formulation, but appears to have carried over to rubber a relationship found empirically valid for coffee.

The first relationship specified by WG is a simplified vintage production function, relating "potential" output in any year to past investments (or plantings) of trees. This embodies the simplifying assumption that past cultivation inputs (labor, fertilizer) and past harvesting decisions do not significantly affect the maximum output currently obtainable from a given stand of trees. 2/ Furthermore, other current factors, such as labor, are not explicitly included on the assumption that they are used in fixed proportion to the stock of trees--the proportion varying only with the age of the tree stock--and other cooperating factors are assumed to be present in such abundance as to guarantee full utilization of the stock. Thus, all potential output is assumed to be harvested. 3/

Following WG, let I_{t-i} represent the number of trees planted i years ago and surviving to year t. Potential output, Q_t^*, is assumed to be a linear combination of past surviving plantings with coefficients, $\delta(i, t)$, representing the yield per tree for stock of age i in year t, which depend not only on the biological age-yield profiles of the trees but also on any improvements in varieties over time or changes in agronomic practices (planting densities, tapping systems, etc.). Thus, we may write

$$(6) \qquad Q_t^* = \sum_{i=0}^{n} \delta(i,t) \cdot I_{t-i} ,$$

where n is the maximum length of life of a tree, and Q_t^* represents the maximum output 4/ attainable at time t given past plantings less removals and losses due to disease, pests, etc. Removals are in fact largely related to replanting decisions. These play little role in the WG formulation--see Arak

(1969) for a discussion of removal practices on Brazilian coffee--but, as we shall see, are a critical element in the determination of Sri Lankan rubber supply. In the WG specification technical change is also ruled out, so that $\delta(i,t) = \delta_i$ is independent of t. Also, if δ_i is zero for $i > n$ and for $i < n$ includes a factor reflecting the probability of survival, then I_{t-i} may be taken as plantings in year t-i excluding all removals, as below. 5/

As WG point out, data on the planting of new trees, whether as replacements for uprooted old trees or as a net expansion of area under cultivation, are rarely available--an exception being our data on area new planted and replanted. Thus, the usual practice, as in the Nerlove model, is to explain the total area under cultivation by a stock demand function. WG follow this practice but derive such a stock demand function from a formal optimizing model under a series of assumptions. In their model, it is assumed that expected discounted net revenue

(7) $V = \sum_{t=0}^{\infty} (1+r)^{-t}[(p_t^e - h_t^e)\, Q_t^* - F_t - f(I_t)]$, where

r = the subjective rate of discount,

p_t^e = the expected price of the crop in t, 6/

h_t^e = the expected unit cost of harvesting in t,

Q_t^* = potential output in t as defined in (1), 7/

F_t = fixed costs of maintaining a planting in t,

I_t = new planting in t (the same as I_t in (6) only if removals and losses are excluded), and

$f(I_t)$ = a nonlinear cost of planting function, such that $f' > 0$ and $f'' > 0$.

The first-order conditions for a maximum of V subject to (6) yield the result

$$(8) \qquad f'(I_t) = \sum_{i=0}^{n} (1+r)^{-i} (p^e_{t+i} - h^e_{t+i}) \delta_i \equiv R^e_t .$$

That is, investment in new plantings should continue until the marginal cost of planting an additional tree equals the expected discounted net revenue from the future production of that tree. The importance of the nonlinearity of f is now apparent. If investment could be carried on at constant unit costs irrespective of the amount undertaken, the investment under those circumstances would not take place at all if the right side of (8) were less than the left and would increase to that associated with the available land if it were greater than the left.

It is difficult to justify the nonlinearity of the investment cost function as the sole basis for determining new plantings (in WG) or replantings (more generally). Indeed, a more general approach would involve comparison of the expected discounted net revenues of the perennial with alternative land uses. In the case of new plantings, these are the revenues which would be generated by alternative crops; in the case of replantings, they are revenues from an existing stand. The decline in yields with age, however, results in increasing marginal opportunity costs as ever younger stands are replanted.

If, however, the function f is nonlinear with $f', f'' > 0$, then via the implicit function theorem, (8) yields the relation

$$(9) \qquad I_t = g(R^e_t) ,$$

where R_t^e is defined as the right-hand side of (8) . For example, if f is quadratic, g is linear.

If a constant density of planting is assumed, the analysis may be recast in terms of newly planted area, $I_t^A = d\ I_t$. If A_t is the area under cultivation in year t and U_t is the area uprooted or abandoned, we have the identity

$$(10) \qquad I_t^A = A_t - A_{t-1} - U_t \ ,$$

hence,

$$(11) \qquad \Delta A_t = d \cdot g(R_t^e) + U_t \ .$$

In the WG formulation, f is assumed to be quadratic so that g is linear, and U_t is assumed to be a random variable independent of R_t^e . Thus the problem becomes estimation of

$$(12) \qquad \Delta A_t = d\beta_0 + d\beta_1 R_t^e + U_t$$

through a suitable representation of R_t^e . Before we turn to WG's solution, note that the area uprooted or abandoned is treated as a disturbance in the equation to be estimated; to the extent that replanting is important in the determination of potential output, U_t will not only be large relative to ΔA_t but will also depend on R_t^e . Hence, it is quite inappropriate to treat it as a classical random error.

As defined in (8), R_t^e is a function of expected future prices and harvesting costs (primarily labor costs), the age-yield profile, and the discount rate. While we have data on relevant wage rates for Sri Lanka, WG choose to model R_t^e by a distributed lag of current and past prices only, since apparently no such wage data exist for coffee workers in Brazil. The final form of the planting equation in the WG formulation is not, however, a general distributed lag formulation for prices based on (12) but, rather, is based on an empirical relationship found for Brazilian coffee during the period 1932-69.[4] This was obtained as follows: A simple distributed lag model was postulated of the form:

$$(13)\quad A_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i A_{t-i} + \sum_{i=0}^{n} \beta_i p_{t-i} + u_t$$

and estimated using ordinary least squares. However, evidence of serial correlation was found in the calculated residuals. The model was then reestimated assuming first-order serial correlation of u_t, but none was found. Lags in A_t greater than two and in p_t greater than zero were found to be insignificant and the coefficients of A_{t-1} and A_{t-2} approximately sum to one, with the coefficient of A_{t-1} being greater than one. This suggests the <u>empirical relationship</u>:

$$(14)\qquad \Delta A_t = \alpha_0 + \alpha_1 \Delta A_{t-1} + \beta p_t + u_t$$

for Brazilian coffee, 1932-1969. As we shall see, Dowling (1979) uses the same relationship for rubber but provides a different motivation.

The final relationship in the WG formulation is a short-run harvesting equation. The assumption, inconsistent with that underlying the derivation of (11), is that a fraction of potential output is actually harvested, with the fraction depending on a short distributed lag in past prices. 8/ The relationship is linearized to yield

$$(15) \qquad Q_t = \gamma_0 + \gamma_1 Q_t^* + \sum_{i=0}^{m} \gamma_{i+2} p_{t-i} + \bar{\gamma} Q_{t-1} ,$$

where Q_t = actual output in t. The term $\bar{\gamma} Q_{t-1}$ is added to represent a biennial bearing cycle, which has been found empirically for coffee (WG, 1973, p. 437).

The final WG model thus consists of the three equations discussed above:

$$(6) \qquad Q_t^* = \sum_{i=0}^{n} \delta_i I_{t-i} ,$$

$$(14) \qquad \Delta A_t = \alpha_0 + \alpha_1 \Delta A_{t-1} + \alpha_2 p_t + u_t ,$$

$$(15) \qquad Q_t = \gamma_0 + \gamma_1 Q_t^* + \sum_{i=0}^{m} \gamma_{i+2} p_{t-i} + \bar{\gamma} Q_{t-1} .$$

By substitution of (14) into (6), using the proportionality of I_t to $\Delta A_t - U_t$ and then into (15), WG find the final reduced-form supply function:

$$(16) \qquad Q_t = c_0 + \sum_{i=0}^{n} c_i p_{t-i} + (\bar{\gamma} + \alpha_1) Q_{t-1} - \bar{\gamma}\alpha_1 Q_{t-2} + v_t ,$$

where v_t is a complicated moving average of the past u_t's and the coefficients c_i, i=1,..., n have the following definitions:

$$
(17) \qquad c_i \begin{cases} = \alpha_2\gamma_1\delta_1 + \gamma_2 , & i=1 \\ = \alpha_2\gamma_1\delta_i + \gamma_{i+2} - \alpha_1\gamma_{i+1}, & i=1,\ldots,m \\ = \alpha_2\gamma_1\delta_{m+1} - \alpha_1\gamma_{m+2}, & i=m+1 \\ = \alpha_2\gamma_1\delta_i, & i>m+1 \end{cases}
$$

The output-response-to-price coefficients, c_i, have a simple interpretation in the case $\alpha_1 = 0$, which corresponds to the long-run equilibrium solution for Brazilian coffee, 1932-1969, obtained from the empirical relation (8): namely, for the period of immaturity when $\delta_i = 0$, they represent the short-run price response of harvesting decisions γ_2, γ_3,..., but after this point (three years in the case of coffee), they are proportional to the age-yield curve. Even if α_1 is not zero, if m is small relative to the period over which trees produce, after the point at which γ_i becomes zero (i > m) the coefficients will reflect primarily the age-yield profile.

WG estimate a reduced-form equation (14) using an Almon lag of length 9 with a fourth-order polynomial and obtain a lag shape very similar to the age-yield profile after 3 years, the age at which a coffee tree begins to bear. The sum of the absolute value of the price coefficients is highly significant, indicating substantial long-run response to price. A likelihood-ratio test is employed to test the restrictiveness of the Almon lag polynomial imposed and is found insignificant. On this basis the authors conclude that the results offer ". . . striking confirmation of the predictions of the

theory. . ." and advocate use of their appproach for the general study of supply response of tree crops.

c. Dowling (1979) on rubber

In recent work on supply response for perennial crops, variants of the WG formulation have been widely applied: Parikh (1979) on coffee, Dowling and Jessadachat (1979) on sugar cane, and Dowling (1979) on rubber. On rubber, Dowling's study for Thailand and the work of Grilli et al. cited earlier represent the current state of the art. In contrast to the latter, Dowling's investigation is explicitly based on the WG formulation for coffee. However, Dowling derives his reduced form in a slightly different way, but obtains an almost identical estimating equation (it lacks only a term in Q_{t-2}). His derivation permits an alternative interpretation of the coefficients of lagged prices. Dowling's reduced form is obtained as follows:

As in WG, Dowling begins with a potential output equation

$$(18) \qquad Q_t^* = \sum_{i=0}^{\infty} \delta(i,t)\, I_{t-i},$$

where after some age, say n years, $\delta(i,t) = 0$, i.e., the oldest trees no longer yield.

All planting is assumed to be new planting, and, in year t is represented as a distributed lag function of past prices

$$(19) \qquad I_t = \beta_0 + \sum_{i=0}^{\infty} \omega_i p_{t-i} \cdot$$

It is not, as in WG, explicitly derived by equating the marginal cost of new investment to the expected present value of future net revenue--see equation (8) and (9). This leads to a subtle difference in the interpretation of the distributed lag coefficients: Dowling simply assumes the standard geometric form of the distributed lag model,

$$(20) \qquad \omega_i = \beta\phi^i \ , \ 0 < \phi < 1 \ ,$$

obtained from an adaptive expectation model for prices, and thus writes

$$(21) \qquad I_t = \beta_0 + \frac{\beta p_t}{1 - \phi L} \ ,$$

where L is the lag operator. Assuming no replanting and replacing I_t by the change in area under cultivation, ΔA_t , then leads to exactly the same form that WG found empirically valid for Brazilian coffee:

$$(22) \qquad \Delta A_t = \beta_0(1-\phi) + \beta p_t + \phi \Delta A_{t-1},$$

or, equivalently,

$$(23) \qquad \Delta A_t = \beta_0 + \frac{\beta p_t}{1 - \phi L} \ .$$

The difference between Dowling and WG is not in the form of the relationship for change in area under cultivation, but rather its deviation. Both neglect uprooting and abandonment, but WG start with a general distributed lag formulation for investment and derive an equation identical to (22) as an

empirical approximation for Brazilian coffee, whereas Dowling obtains it by the ad hoc assumption of adaptive expectations. As we show in the next section, (22) represents a very poor formulation for changes in area in rubber under cultivation in Sri Lanka, due to the dominance of uprooting and replanting decisions.

Finally, Dowling hypothesizes a linear relationship between current output, Q_t, potential output, Q_t^*, and a short, nonadaptive distributed lag in past prices:

$$(24) \qquad Q_t = \gamma_0 + \gamma_1 Q_t^* + \sum_{i=0}^{m} \gamma_{i+2} p_{t-i} ,$$

which is identical to WG's formulation (15) except for the term in lagged output, Q_{t-1}, which WG include to represent a two-year bearing cycle for coffee.

To obtain the final reduced-form supply function, Dowling replaces Q_t^* in (24) by (18) and ΔA_t by $\beta p_t/(1-\phi L)$, which is equivalent to (22), arriving at the result:

$$\begin{aligned}(25) \qquad Q_t = {} & \tilde{\gamma}_0(t) + \phi Q_{t-1} + (\gamma_1 \beta \delta(0,t) + \gamma_2) p_t \\ & + (\gamma_1 \beta \delta(1,t) + \gamma_3 - \phi \gamma_2) p_{t-1} \\ & + (\gamma_1 \beta \delta(2,t) + \gamma_4 - \phi \gamma_3) p_{t-2} \\ & + \ldots\end{aligned}$$

$$+ (\gamma_1\beta\delta(6,t) + \gamma_8 - \phi\gamma_7)p_{t-6}$$

$$+ \ldots$$

$$+ (\gamma_1\beta\delta\ (m,t) + \gamma_{m+2} - \phi\gamma_{m+1})\ p_{t-m}$$

$$+ (\gamma_1\beta\delta\ (m+1,t) - \phi\gamma_{m+2})p_{t-m-1}$$

$$+ (\gamma_1\beta\delta(m+2,t))p_{t-m-2}$$

$$+ \ldots$$

$$+ (\gamma_1\beta\delta(n,t))p_{t-n}\ ,$$

where $$\tilde{\gamma}_o(t) = \gamma_o + \gamma_1\beta(1-\phi L) \sum_{i=0}^{\infty} \delta(i,t)\ .$$

Since $\delta(i,t) = 0$ for $i = 0, 1, \ldots 6$ or 7 in the case of rubber, the first six or seven coefficients reflect the coefficients of price in the harvesting equation (24). Moreover, if the lags involved in this equation are not very long for prices, so that m is much less than n , where n is the maximum age beyond which a rubber tree does not produce, it is apparent that, as in the case of the WG formulation, the coefficients reflect the age-yield profile. Dowling, as do WG, simplify the model by assuming that the age-yield profile does not change over time.

Because of the length of the lag and because the age-yield profile for rubber is alleged to be relatively flat after 13 years, Dowling takes first differences of (25) to obtain

$$
\begin{aligned}
(26) \qquad Q_t = (1+\phi)\, Q_{t-1} - \phi Q_{t-2} &+ (\gamma_1\beta\delta_0 + \gamma_2)p_t \\
&+ (\gamma_1\beta(\delta_1 - \delta_0) + (1+\phi)\gamma_2 - \gamma_3)p_{t-1} + \cdots \\
&+ (\gamma_1\beta(\delta_{m+2} - \delta_{m+1}) + (1+\phi)\gamma_{m+1} - \gamma_{m+2})p_{t-m-1} \\
&+ (\gamma_1\beta(\delta_{m+3} - \delta_{m+2}) + \phi\gamma_{m+2})p_{t-m-2} \\
&+ \gamma_1\beta(\delta_{m+4} - \delta_{m+3})p_{t-m-3} \\
&+ \cdots \\
&+ \gamma_1\beta(\delta_n - \delta_{n-1})p_{t-n} \,.
\end{aligned}
$$

The differences between the δ's will be small or zero both when the δ's are zero (up to 6 or 7 years) and when the age-yield profile is relatively flat (from 13 to more than 30 years). Thus if m is small, the coefficients of prices lagged less than n years will reflect the distributed lag in the harvesting equation (24). After that point, they will be positive, reflecting the rising age-yield profile to lag 13. Then the coefficients should be zero until very long lags, at which point the age-yield profile declines so that the coefficients become negative.

Dowling estimates equation (26) with a constant term, which implies a linear trend, and without imposing the restriction that the coefficients of Q_{t-1} and Q_{t-2} sum to one. He finds that the sign of the coefficient of Q_{t-2} is positive in every case estimated, but that the sum of the coefficients of Q_{t-1} and Q_{t-2} is close to one in most cases. This suggests a

misspecification of the distributed lag formulation in equation (22). Various specifications of the Almon lag form are estimated (with and without end-point constraints, 3rd-and 4th-order polynomial), and different periods chosen: 1915-39 and 1950-71 or 1950-1975, or 1950-75 alone. The sum of the lag coefficients for prices ranges from a low of 1.117 to a high of 12.527, suggesting a relatively large long-run response to price, although the estimates are highly sensitive to the choice of period and specification of the lag distribution. The shape of the lag distribution does approximate what was expected, but the timing of the positive and negative portions appears strange in the light of what is known about typical age-yield profiles. The low-order coefficients are positive but fall off rapidly, becoming negative at lag 3. These negative values persist until lag 9 or 10, with a trough around lag 5. After lag 9 or 10 the coefficients become positive and increasingly significant; they are assumed to be zero after lag 14 with an end-point constraint to zero at lag 15 in some estimation equations.

That there should be much of any lag in the harvesting equation is puzzling since the costs are essentially current labor costs, but if labor is quasi-fixed, some lag effects are not implausible. The typical age-yield profile for rubber, however, suggests that the coefficients should be positive only after the yield profile starts to rise, reaching a peak between six or seven years when the trees begin to yield and 13 or 14 years when yields level off. Indeed, the age-yield profile we have estimated from the Sri Lankan estate data shows yields rising abruptly from six years to a peak at 16 years, then a gradual fall to age 37 and a more rapid fall after that. The highest point in the differences, $\delta_{i+1} - \delta_i$, occurs between i = 7 and i = 8, but yield

is negligible before i = 6. In our own analyses, we make direct use of the age-yield profile in estimation of the equations of the model. Possibly significant uprooting and replanting such as that found in Sri Lanka could account for some of Dowling's anomalous results. Indeed, the treatment of replanting by WG and Dowling is inadequate, a gap we attempt to fill in Section 4.

3. Replication of the Grilli et al. and Dowling Analyses with Sri Lankan Data

The standard Nerlove model given in equations (1) - (3) leads to a regression of area under cultivation on current or lagged price, and area lagged one year and two years. Replacing area under cultivation by observed output, we find for the period 1947-79:

$$(27) \qquad Q_t = \underset{(2.01)}{21904.9} + \underset{(3.84)}{0.6205}\, Q_{t-1} + \underset{(1.78)}{0.2967}\, Q_{t-2} - \underset{(2.20)}{10167.6}\, p_{t-1},$$

$$\bar{R}^2 = 0.887 , \qquad\qquad D.W. = 2.053 .$$

Values in parentheses are t-ratios. Prices used were the yearly average Columbo auction RSS #1 price deflated by the Columbo CPI. Quantity data used were total annual production as reported in the Administrative Report of the Rubber Controller, 1947-1979. Note that, in the standard Nerlovian model, the coefficient of Q_{t-2} should be $-(1-\beta)(1-\gamma)$, that is, negative if the coefficients of expectation and adjustment both lie between zero and one. Nonetheless, the coefficient is positive and significant at the 10% level

(although not at the 5% level). Thus the hypothesis that one of the two dynamic parameters is less than zero is not rejected at the 10% level. Moreover, the coefficient of price is negative and significantly different from zero at better than the 5% level; the price elasticity of supply implied is approximately -0.9. Thus the standard Nerlovian specification adopted in simplified form by Grilli et al. is clearly inadequate to describe rubber supply in Sri Lanka. 9/

We have also attempted to replicate Dowling's rubber model using our data for Sri Lanka. In the final reduced form estimated, the model involves only a distributed lag on deflated prices and lagged values of the dependent variable. It differs from the original WG formulation for coffee only in that it provides a different justification for the lagged values of the dependent variable included and it extends the lag in price over a much longer period to account for the differences in the age-yield profiles between rubber and coffee. The age-yield profile for rubber based on data for 49 estates in Sri Lanka over a 10-year period (presented in the next section) shows virtually no yield for the first six years, then a rapid rise to a peak at 15 years and a more rapid decline thereafter. Technological progress has not only increased yields, but has also moved forward the period at which significant yields are achieved. Dowling's procedure is to experiment with lags of various lengths (Almon forms with and without end-point restrictions, using 3rd- and 4th-order polynomials) and choose the best-fitting result. We have repeated this procedure to obtain, for 1943-79, a 4th-degree polynomial Almon lag with no end-point restriction, yielding the following equation:

$$
\begin{array}{llll}
(28) & Q_t = 39810.5 & + 0.1655\, Q_{t-1} & + 0.3781\, Q_{t-2} \\
 & \quad (0.78) & \quad (0.81) & \quad (1.74) \\
 & + 29090\, p_t & + 2440\, p_{t-1} & - 12740\, p_{t-2} \\
 & \quad (2.99) & \quad (0.70) & \quad (2.21) \\
 & - 19330\, p_{t-6} & - 19830\, p_{t-4} & - 16410\, p_{t-5} \\
 & \quad (2.80) & \quad (3.20) & \quad (3.63) \\
 & - 10900\, p_{t-6} & - 4755\, p_{t-7} & + 901\, p_{t-8} \\
 & \quad (3.60) & \quad (1.58) & \quad (0.23) \\
 & + 5303\, p_{t-9} & + 8033\, p_{t-10} & + 9026\, p_{t-11} \\
 & \quad (1.14) & \quad (1.73) & \quad (2.24) \\
 & + 8564\, p_{t-12} & + 7281\, p_{t-13} & + 6160\, p_{t-14} \\
 & \quad (2.72) & \quad (2.73) & \quad (2.24) \\
 & + 6536\, p_{t-15} & + 10090\, p_{t-16} & \\
 & \quad (2.32) & \quad (2.60) &
\end{array}
$$

$\bar{R}^2 = 0.932$ D.W. = 2.82

The sum of the lag coefficients on prices is 9470 with a standard error of 26876. The implied price elasticity of supply at the mean price and quantity for 1947-79 is +0.81.

$\frac{\lambda}{1-\lambda}$ $(1-\lambda) = .1655$ $.8345$

The coefficient of Q_{t-2} is positive and significantly different from zero at about the 10% level. If we ignore the term in Q_{t-2} and interpret the coefficient of Q_{t-1} as one minus a coefficient of adjustment, the implied long-run elasticity of supply is +0.97, which is much higher than any found by Grilli et al. However, this interpretation, which is also consistent with the high value of the Durbin-Watson statistic obtained, is not consistent with the WG interpretation of the coefficients of lagged prices in terms of the age-yield profile.

The coefficients of lagged prices may be compared with the interpretation suggested by equation (26). Ignoring the term on Q_{t-2}, the coefficient, ϕ, must be in the interval [0,1] to satisfy the assumptions of the standard adaptive expectations form; however, according to (28), $\phi = -.8345$. Also, because yield is effectively zero in the first six years, the coefficients on price after the first represent $(1+\phi)\ \gamma_i - \gamma_{i-1}$ should be positive and declining if ϕ is small and $\alpha_2, \ldots, \alpha_8$ are declining; since $\phi = -.8345$ from the coefficient of Q_{t-1}, and $\alpha_2 = 29090$ from the coefficient on p_t, $\alpha_3 = 2374$ and $\alpha_4 = 13{,}133$. In general, these results are inconsistent with a relatively short declining lag in prices in the harvest equation. Moreover, after lag 6 or 7, the coefficients should be increasingly positive, reflecting the sharply rising portion of the age-yield profile until 16 years. But, the coefficients on lags 6 and 7 are negative which would indicate that the lag in the harvesting equation is unusually long; also, the coefficients start to decline after lag 11 which is inconsistent with the age-yield profile obtained from our sample of 49 estates (see figure 5). Consequently, we conclude that equation (26) based on the Dowling formulation

of WG is not a useful representation of the reduced-form supply function for rubber in Sri Lanka.

In order to see whether the unrestricted first-difference form of the WG equation was causing the difficulty, we also fit an equation imposing the restriction that the coefficents of Q_{t-1} and Q_{t-2} must sum to one:

$$
\begin{aligned}
(29) \quad Q_t - Q_{t-1} = & \quad - \underset{(2.22)}{41826} \quad + \underset{(2.51)}{0.4939} \; [Q_{t-1} - Q_{t-2}] \\
& - \underset{(1.98)}{15140} p_t \quad + \underset{(1.48)}{4405} p_{t-1} \quad - \underset{(0.89)}{1962} p_{t-2} \\
& - \underset{(1.8)}{5012} p_{t-3} \quad - \underset{(2.06)}{5667} p_{t-4} \quad - \underset{(2.08)}{4726} p_{t-5} \\
& - \underset{(1.60)}{2861} p_{t-6} \quad - \underset{(0.37)}{625} p_{t-7} \quad + \underset{(0.82)}{1557} p_{t-8} \\
& + \underset{(1.57)}{3380} p_{t-9} \quad + \underset{(2.04)}{4665} p_{t-10} \quad + \underset{(2.25)}{5356} p_{t-11} \\
& + \underset{(2.19)}{5521} p_{t-12} \quad + \underset{(2.01)}{5352} p_{t-13} \quad + \underset{(1.96)}{5163} p_{t-14} \\
& + \underset{(2.03)}{5394} p_{t-15} \quad + \underset{(1.56)}{6608} p_{t-16} \\
& \bar{R}^2 = 0.526 \qquad\qquad D.W. = 2.52
\end{aligned}
$$

A likelihood-ratio test (λ = 256.733 - 211.141 = 45.952 with 1 degree of freedom) decisively rejects the null hypothesis that the coefficents of Q_{t-1} and Q_{t-2} in the unrestricted case, (28) sum to one. Moreover, the coefficients of lagged prices after lag 7 fail to reflect the expected shape of the

age-yield profile under the assumption that the effect of lagged prices in the harvest equation is of relatively short duration, as discussed above.

Because we have statistics on area (recorded in the Administrative Report of the Rubber Controller, 1947-79), we can test directly one of the key assumptions of the Dowling adaptation of the WG formulation, namely equation (22). Our estimate for 1947-79, in undifferenced form, is

$$A_t = \underset{(0.63)}{49475.6} + \underset{(5.48)}{1.009}\, A_{t-1} - \underset{(0.42)}{0.086}\, A_{t-2} + \underset{(0.35)}{908}\, p_t \tag{30}$$

$$\bar{R}^2 = 0.80 \qquad\qquad D.W. = 2.04$$

Dowling does not actually include A_{t-2} in his equation, but we follow WG, who do. The coefficient of A_{t-2} is insignificantly different from zero and the coefficient of A_{t-1} is insignificantly different from one. This means that (22) holds with $\beta = 0$ and $\phi = 0$, i.e., area follows a random walk for Sri Lanka in this straight-forward estimation of the Dowling-WG formulation.

This result is hardly surprising for Sri Lanka because the total acreage series has been virtually constant (see Figure 1). The negligible change in total acreage over the period 1947-79 is the result of the predominance of replanting rather than new planting. A large replanting subsidy was introduced in 1953, and the bulk of planting activity has involved uprooting existing older stands and replanting with higher yielding clonal varieties. No model that takes changes in acreage as a measure of new investment and neglects uprooting for replanting and abandonment can possibly serve as an adequate representation of rubber supply response in Sri Lanka. In the next section, we formulate and estimate an extension of the WG

formulation that emphasizes the replanting decision as a major source of rubber supply response in Sri Lanka.

4. Data Available and a Model of Rubber Supply in Sri Lanka

The Data

Figure 1 shows, in addition to total acreage under rubber 1940-79, that part in smallholdings, small estates, and large estates. The stability of the total masks a significant decline in the area under rubber in large estates and an offsetting increase in smallholdings. 10/

Figure 2 shows total plantings of rubber broken down by new planting and replanting. With the advent of the Rubber Replanting Subsidy Scheme in 1953, rubber plantings have been primarily replantings and, under the scheme, all replantings were required to be high yielding clonal varieties. Thus, by now almost all rubber stands, except for the very old trees, consist of clonal varieties. However, these have consistently improved over time so that, as can be seen from Figure 3, total production of rubber in Sri Lanka has increased markedly over time--particularly since the early 1960s--despite the stability of the total area under rubber. This reflects the higher yield associated with replantings in the mid-50s on, which begin yielding after a gestation period of six years. Although there was, also, a significant amount of new planting of high-yielding varieties throughout the 1950s, most planting consists of uprooting existing stands and replanting with clonal varieties,

FIGURE 1

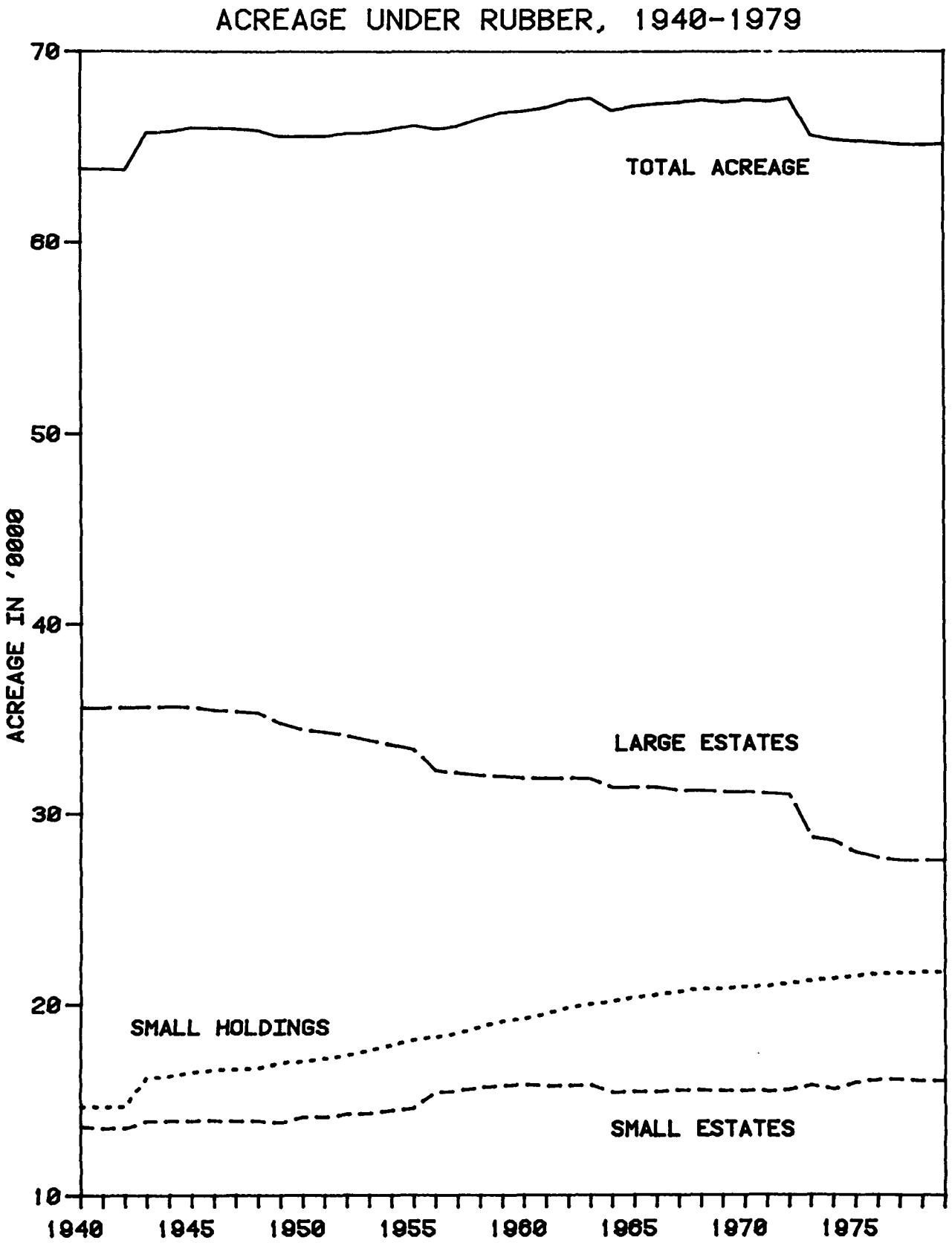

ACREAGE UNDER RUBBER, 1940-1979
ACREAGE IN '0000
70
60
50
40
30
20
10
TOTAL ACREAGE
LARGE ESTATES
SMALL HOLDINGS
SMALL ESTATES
1940
1945
1950
1955
1960
1965
1970
1975

FIGURE 2

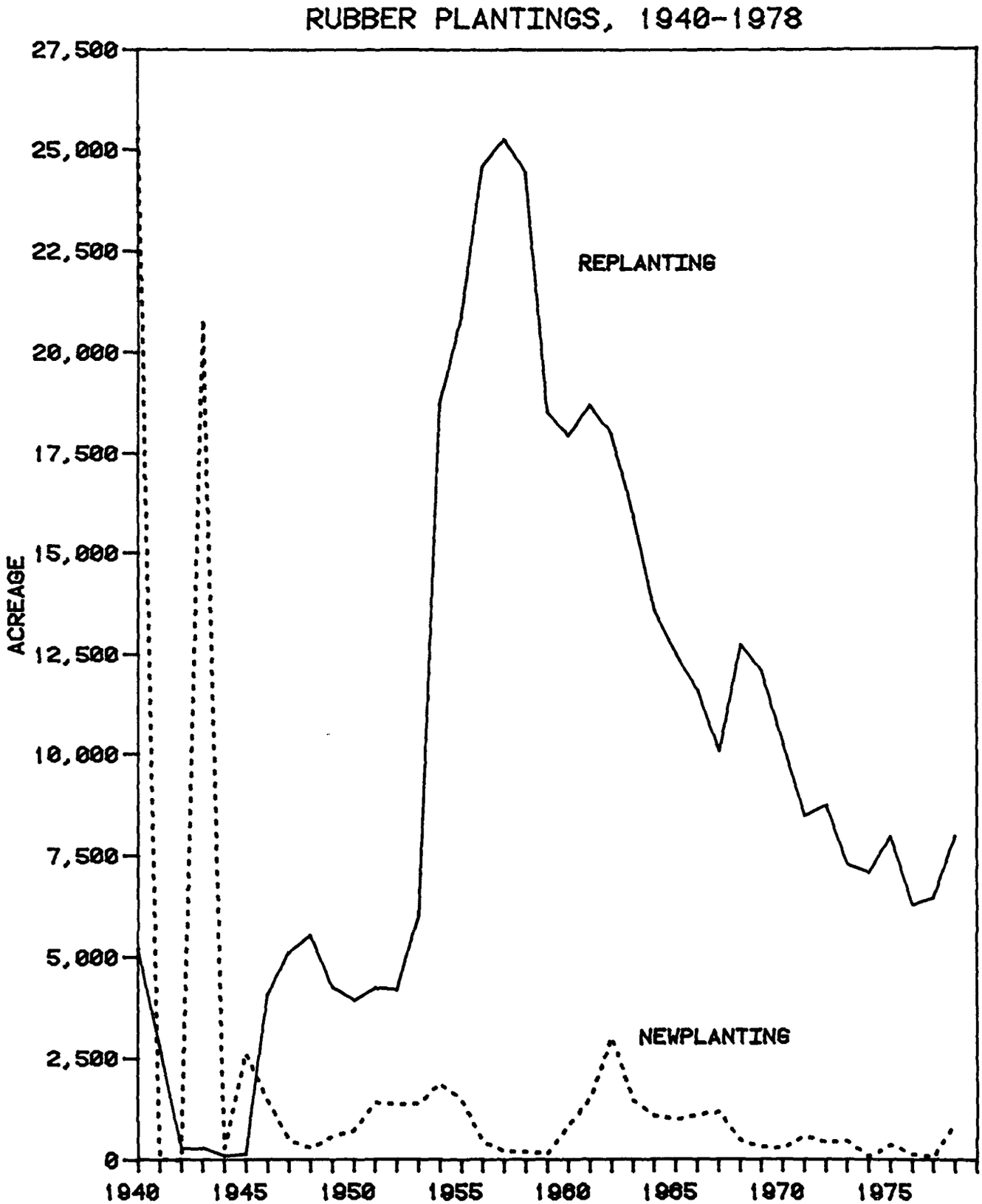
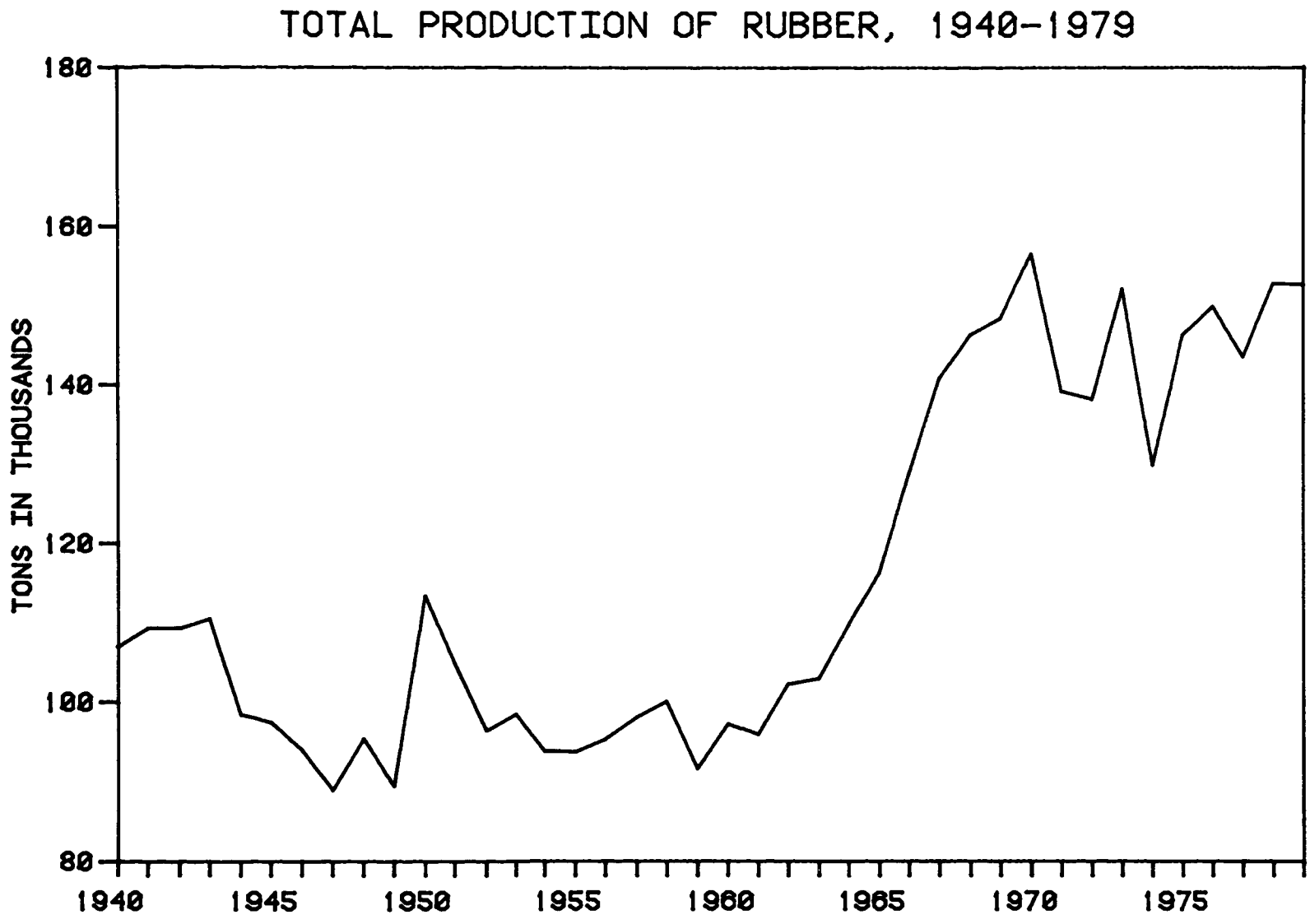

RUBBER PLANTINGS, 1940-1978
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
0
ACREAGE
REPLANTING
NEWPLANTING
1940
1945
1950
1955
1960
1965
1970
1975

FIGURE 3

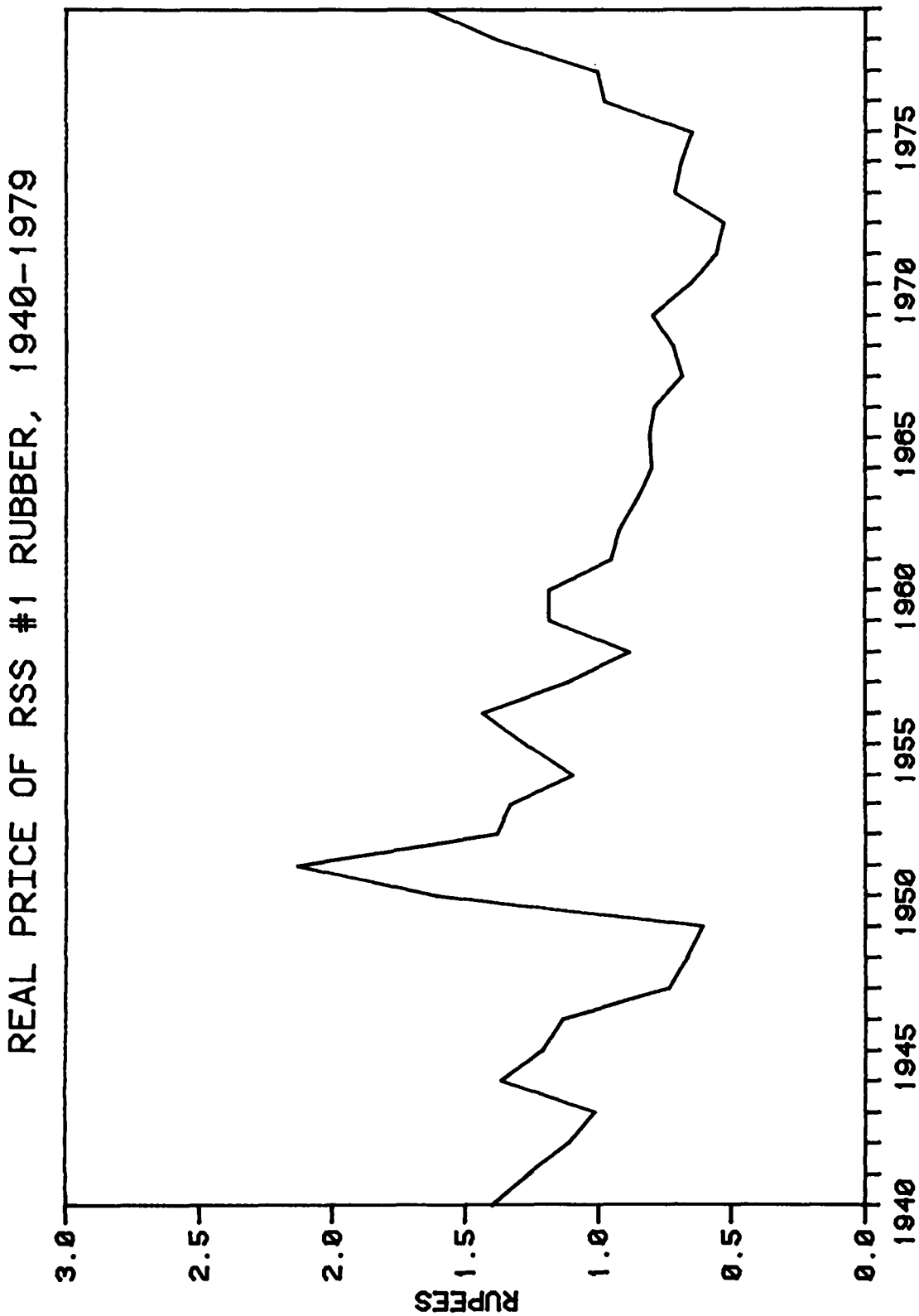

TOTAL PRODUCTION OF RUBBER, 1940-1979
TONS IN THOUSANDS
180
160
140
120
100
80
1940
1945
1950
1955
1960
1965
1970
1975

especially beginning in 1953 when substantial subsidies for such replanting were introduced. Fluctuations over time in the amount of replanting have also been great. Thus, no rubber supply model for in Sri Lanka that fails to emphasize this aspect of supply behavior can begin to capture the essential elements of the supply response. The replications of Grilli et al and Dowling using Sri Lankan data, reported in the previous section, simply reflect the trends in production and prices revealed in Figures 3 and 4.

Finally, Figure 5 plots the average yield of rubber latex per acre associated with stands of different ages for 49 large rubber estates over the 10-year period 1970-79. No allowance is made for difference in clonal variety, type of soil, elevation, tapping practice, or other factors. In subsequent research, we shall attempt to separate the effect of age on yield from aspects of cultivation and harvesting practices. For present purposes, however, we shall be content to employ the age-yield profile, which has been described in the previous section, to characterize the underlying technology.

In addition to data on prices, production, area under cultivation distributed by age, and replanting, new planting, etc., we have information on wages, the general price level, some input prices, and replanting subsidies. Our model at this stage is designed primarily to exploit the detailed information on planting and the age distribution of the stock of trees. In further work, we hope to utilize more fully the detailed agronomic information from the Bank's survey of 49 estates and the regional and varietal breakdowns of area under cultivation made possible by our sources. (A more detailed description of the data, other than the area statistics, is given in Appendix B.)

FIGURE 4


REAL PRICE OF RSS #1 RUBBER, 1940-1979
RUPEES
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1940
1945
1950
1955
1960
1965
1970
1975

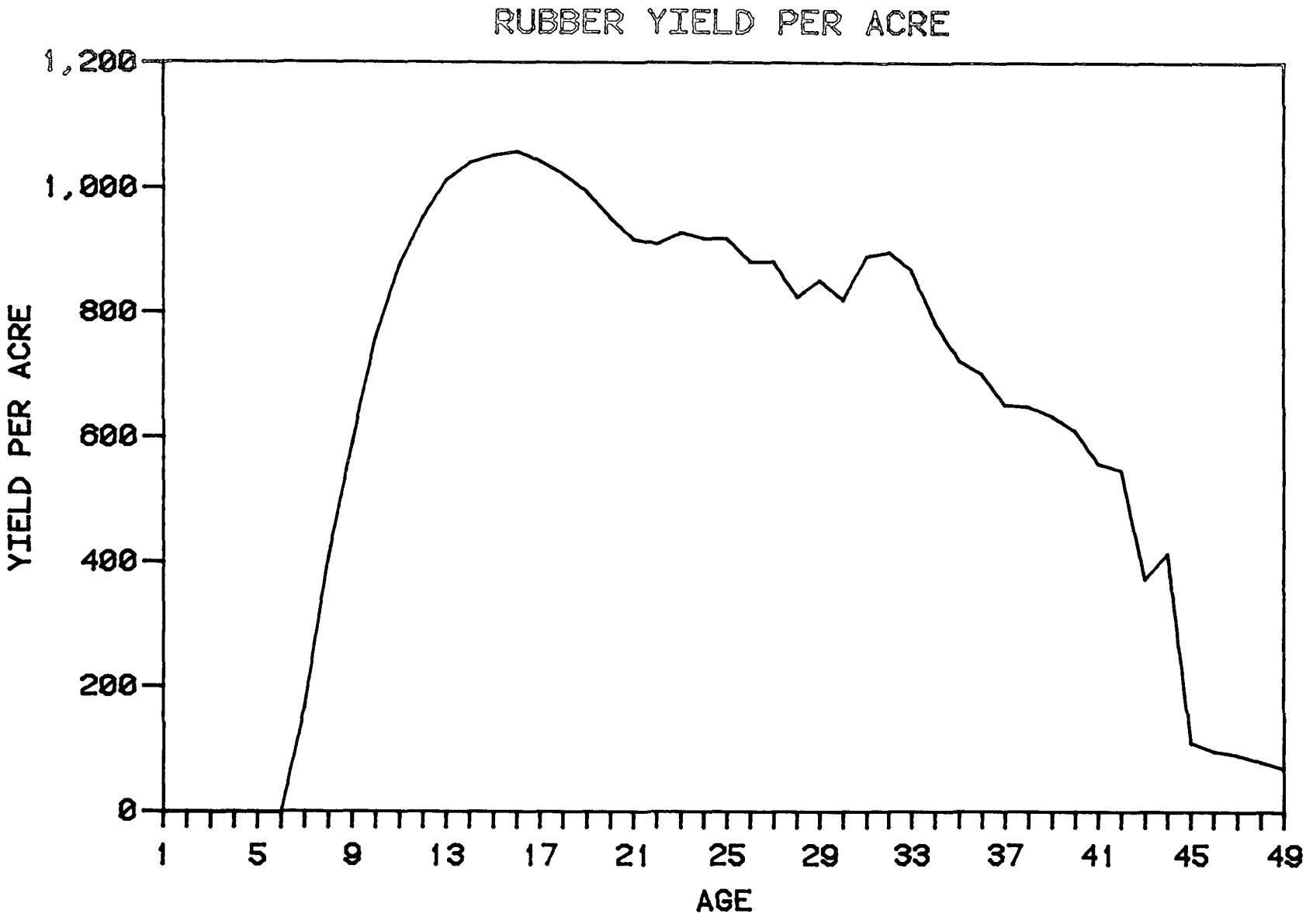

RUBBER YIELD PER ACRE
YIELD PER ACRE
1,200
1,000
800
600
400
200
0
1
5
9
13
17
21
25
29
33
37
41
45
49
AGE

FIGURE 5

The Model

The original WG formulation consists of three equations: (1) A new planting or investment equation, more or less based on dynamic optimization of the discounted stream of future net revenues; (2) a "potential output" equation, which summarizes the technological relation between the stock of trees by age and output; and (3) a harvesting equation, which relates potential output to realized output. Our model modifies the WG formulation to emphasize replanting and also includes a new planting equation. Since we have an explicit age-yield relationship, as well as the actual age distribution of the tree stock in each year, we can calculate potential output directly rather than introduce it as a separate equation of the model with unknown parameters $\delta(i,t)$. 11/ As do WG, we have a harvesting equation. Finally, we have a separate equation for new planting, which corresponds to the WG investment equation. Unlike WG, our data permit estimation of each equation separately rather than a single reduced-form supply equation. Separate estimation and the fact that we emphasize replanting decisions rather than treating them residually distinguish our analysis from the WG formulation and Dowling's application of it to rubber in Thailand.

We define the following variables:

A_t = the total area under rubber cultivation in year t;

R_t = the area replanted in year t (assumed to equal the area uprooted); 12/

p_t^e = "expected normal" price of rubber (deflated) in year t;

p_t = current rubber price (deflated) in year t;

s_t = current subsidy per acre replanted (deflated) in year t;

w_t = wage rates for tapping and maintenance labor (deflated) in year t;

x_t = other relevant variables to be specified later;

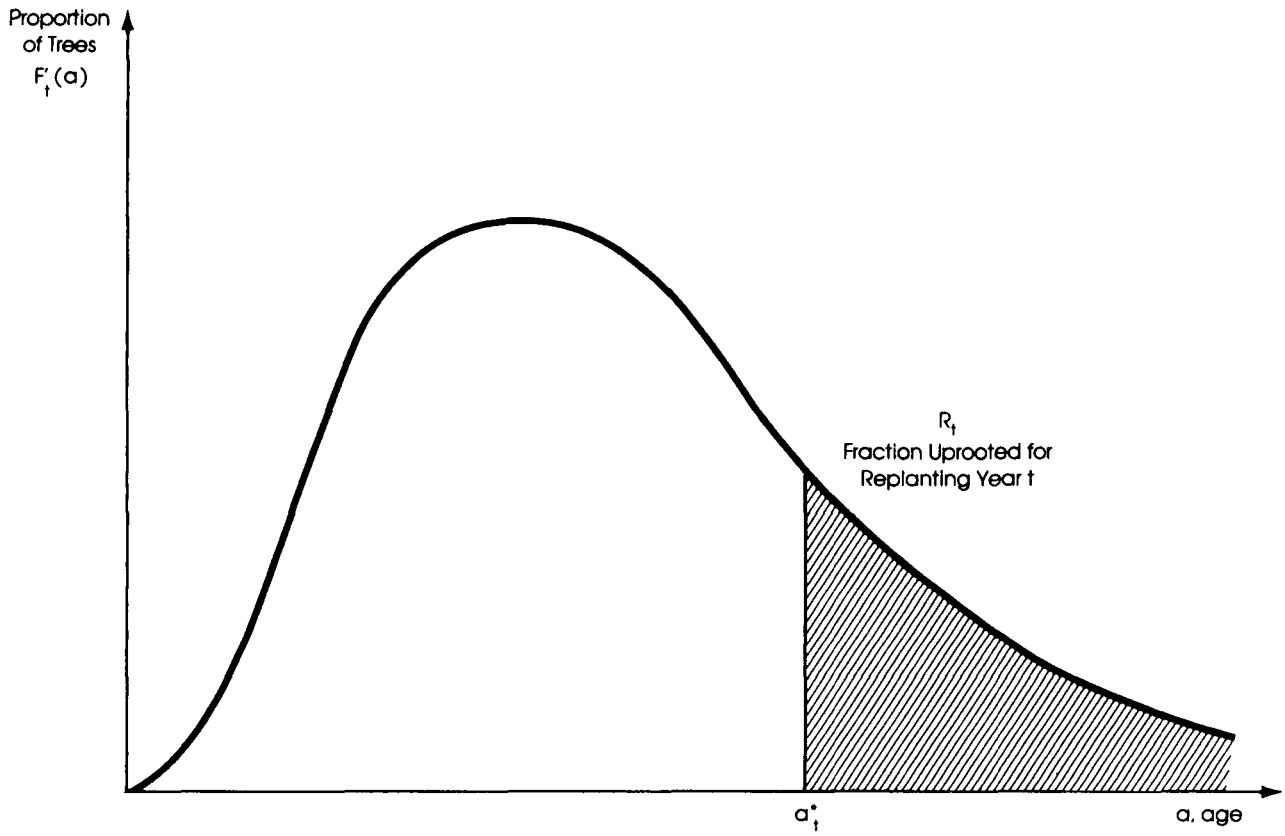
$F_t(a)$ = the current empirical cumulative age distribution of area under cultivation in year t, i.e., the proportion of total cultivated area in year t less than or equal to a years of age;

a_t^* = "truncation point" of the age distribution in year t, such that the areas greater than age a are eligible for replanting.

In deciding whether or not to uproot and replant a stand of rubber trees of a given age, rubber growers must compare the current net revenue (price times yield minus costs) and discounted future expected net revenues per acre from the existing stand with that which may be expected from the proposed replacement over some planning horizon (see Perrin (1972)). 13/ The net revenues from continuing cultivation of the present stand depend on its age and the age-yield profile for the particular variety (or mix of varieties) of which it is composed. The revenues from the proposed replacement depend on the expected age-yield profile for the variety to be replanted and the costs of the uprooting-replanting operation. Both depend on current rubber prices and a sequence of expected future prices, which extend into the distant future because of the long period over which a rubber tree is expected to yield. Given the decline in yield which occurs after age 15 years (although not

FIGURE 6

Empirical Age Distribution



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uniformly for all varieties) and the steady improvement of the expected yields of new clonal varieties, it will obviously pay at some point in the life-cycle of a stand to take it out and replant with the then currently available clonal variety. If all stands were internally uniform with respect to age and variety and all growers faced equal price opportunities and cost constraints and had similar expectations, only older trees would be removed. Thus we can imagine, as in Figure 6, that only the tail of the age distribution is removed in any year, but the point at which the truncation occurs, a_t^* , depends on a number of other factors, as indicated above.14/

Because replanting occurs for other reasons, such as storm damage and disease, and because expectations, opportunities, and constraints are not exactly identical for each grower, we would not expect replanting to be exactly proportional to $1 - F_t(a_t^*)$. Assume that the former is linearly related to the latter with a stochastic error term:

$$(31) \qquad R_t = \tilde{\alpha}_0 + \tilde{\alpha}_1 A_t \, [1-F_t(a_t^*)] + \tilde{u}_t$$

The term $\tilde{\alpha}_0 + u_t$, for example, may be supposed to represent storm and disease damaged replacements; $\tilde{\alpha}_1$, not necessarily equal to one, represents any systematic bias involved in not replacing all trees of age greater than a_t^* . Of course, all of these departures from the strict replacement model will show up in the next period's empirical age distribution, $F_t(a)$, but since we have data on this distribution we do not need to model the connection between $F_{t+1}(a)$ and $F_t(a)$ explicitly.15/

In what follows we assume that growers expect all future prices to be the same ("expected normal" price) but not necessarily equal to the current

price; that the current price is an adequate proxy not only for what growers currently receive but also for their expectations of near-term prices up to roughly the time at which a newly replanted stand can begin to yield significantly; 16/ and that the current wage rate is an adequate proxy for all current and expected future costs, and in particular, for the high labor costs involved in the uprooting-replanting operation. It is clear that growers will compare current prices and near-term expectations, p_t , with longer-term expectations of prices, p_t^e , in order to decide whether to uproot and replant a given stand: the higher the current prices and near-term expectations relative to expected normal price levels, the less replanting will occur; the higher the level of expected normal prices, the more it will pay to replant now. These expectations must be compared with what it will cost for the operation (including the subsidies given to induce growers to switch to higher-yielding varieties.) Thus,

$$(32) \qquad a_t^* = f(p_t - p_t^e,\ p_t^e,\ w_t,\ s_t,\ x_t)\ ,$$

where x_t may have a stochastic component. Substituting (32) in (31) we obtain a highly nonlinear replanting equation that depends not only on the parameters of f, $\tilde{\alpha}_0$, and $\tilde{\alpha}_1$ but also on the empirical age distribution $F_t(a)$ at any time:

$$(33) \qquad R_t = \tilde{\alpha}_0 + \tilde{\alpha}_1\ A_t[1-F_t(f(p_t - p_t^e,\ p_t^e,\ w_t,\ s_t,\ x_t))] + \tilde{u}_t\ .$$

It remains to specify p_t^e . We adopt the simple adaptive expectations model for the determination of "expected normal prices," or long-term price expectations:

$$(34) \qquad p_t^e - p_{t-1}^e = \beta[p_{t-1} - p_{t-1}^e]\ .$$

We could equally well use an alternative fancier formulation, e.g., quasi-rational expectations (see Nerlove et al., 1979), but adaptive expectations appear to work well in a variety of contexts and have the advantage of being consistent with the optimizing model implicitly assumed.

Assuming $\tilde{u}_t$ to be NID(0, σ^2), specifying f parametrically and neglecting any stochastic component in x_t, given data on prices, wages, subsidies, replantings, total area under cultivation, and the empirical age distribution, we could, in principle, form a likelihood function that could be maximized numerically. In fact, this is not hard to do. However, it is computationally expensive. For our preliminary analysis, therefore, we adopted a further approximation: Instead of incorporating all of the empirical age distributions at each stage of the estimation procedure, we chose various measures, such as the area planted to trees over 40 years of age, between 36 and 40, and between 31 and 35.

Let AGE_t = a general variable reflecting such a measure or measures of the tail of $A_t[1-F_t)(a)]$. Our preliminary replanting equation is then not (33) but,

$$(35) \qquad R_t = \alpha_0 + \alpha_1[p_t - p_t^e] + \alpha_2 p_t^e + \alpha_3 w_t + \alpha_4 s_t + \alpha_5 AGE_t + \alpha_6 x_t + u_t.$$

Equation (34) may be used to generate a series on p_t^e given past prices and any value of β in the interval [0,1). Maximum-likelihood estimates of the parameters of (31) can be obtained by searching for β's in this interval in order to find that value giving the highest R^2 for (35), provided we assume $u_t \sim$ NID $(0,\sigma^2)$.

One problem with both the simple and the more complex estimation procedures is that F_t or AGE_t is not really exogenous and independent of $\tilde{u}_t$ or u_t, but given independence of the u's over time these variables will be predetermined.

To "close" the model we must determine production and new plantings.

Technology in this model is given simply by the age-yield profile. We ignore weather, labor inputs, fertilizer use, and, except indirectly by introduction of a time trend, the effects of varietal improvements over time. Since we have an empirical age-yield profile and actual estimates of the age distribution in each year, let y(a) = the yield per acre of rubber trees of age a. 17/ Then the "potential" output, Q_t^*, in year t is given by

$$(36) \qquad Q_t^* \equiv \sum_a y(a)\, F_t'(a)\, A_t \ . \ \underline{18}/$$

Actual production may differ from Q_t^* because of weather conditions, harvesting costs in relation to current prices, prior use of other inputs such as fertilizer, and "slaughter" tapping in anticipation of uprooting and replanting of older stands. In WG and Dowling, a short lag on current prices is included in this equation; however, we have not included a lag for reasons discussed earlier (see footnote 8 and p. 19). Thus our harvesting equation is

$$(37) \qquad Q_t = \beta_0 + \beta_1 Q_t^* + \beta_2 p_t + \beta_3 p_t^e + \beta_4 w_t + \beta_5 t + v_t \ .$$

We expect to find β_1 close to one, β_2 positive, β_3 small and negative, β_4 negative, and β_5 positive.

New planting is the most difficult to model for Sri Lanka since there was virtually none during the period we studied. We do not expect good

results in this case since there is significant variation in the little new planting that occurred only for a brief period in the 1950s. In general we would expect new planting to depend on much the same variables as replanting except that the entire age distribution of the stock, not just the tail matters. Moreover since rubber output is not foregone (only the output of other crops displaced), current prices are not likely to matter much for new planting; longer-term expectations of prices relative to current costs of planting and alternative crops may play some role. 19/ Let N_t = acres newly planted to rubber in year t. We represent the effect of the existing stock by Q_t^*, which weights stands of different ages by their average yields. Our equation is

$$(38) \qquad N_t = \gamma_0 + \gamma_1 Q_t^* + \gamma_2 p_t^e + \gamma_3 w_t + \gamma_4 x_t + e_t.$$

5. Empirical Results

Replanting

We ran a number of regressions along the lines of equation (35) as specified in the preceding section. In initial results, the real wage was always found to be insignificant and was dropped from further analyses. Indeed, on large estates, which account for the bulk of the area under rubber as well as production, labor is a fixed factor in the short run. Since the decision to replant involves short-run costs compared with long-run returns, it is not surprising that the price of a fixed factor is not significant.

Our major problem in formulating an adequate replanting equation was incorporating the effect of the age distribution. As indicated above (footnote 10), there is a substantial discrepancy between the official area

statistics, those figures available from recent censuses, and the figures presented in various reports of the rubber controller. These discrepancies are probably due for the most part to smallholder abandonments at higher elevations and to removals of older vintages of low-yielding seedling varieties. As such, the discrepancy between the official acreage series and various alternatives based on census or other data may be expected to most affect estimates of the very oldest groups. Instead of working with the more complex formulation of (33) involving the empirical age distribution in every year, we broke the tail down into three groups:

AGE40+ = acreage planted with trees older than 40 years;

AGE36-40 = acreage planted with trees between 36 and 40 years old;

AGE31-35 = acreage planted with trees between 31 and 35 years old.

The discrepancy may be expected to affect the results of including AGE40+ more than the other age-distribution variables. Indeed the results with this variable proved to be uniformly bad, but our attempts to distribute the discrepancy, as described in Appendix A, did not lead to results that differ in any significant respect from those using the official data. Either the results are not sensitive to the discrepancy or the method we adopted for distributing it was defective.

Our initial regressions, employing the revised and offical data, indicated that both AGE36-40 and AGE31-35 were positively and significantly related to replanting but that AGE40+ was not significantly related. This finding is no doubt due in part to the fact that much of the over 40 acreage

is in smallholdings; smallholders face different constraints and opportunities than do the managers of large and medium sized estates.

As indicated, we iterated on the coefficient of expectations, β, in calculating p_t^e until we found the best-fitting regression. The reported t-statistics are conditional on the value formed by this procedure.20/ The expected price series was calculated recursively beginning with the last period. We tried several specifications of equation (35) also including the price of low grown tea (an alternative crop). The results for 1944-78 of our best equation, using the revised area statistics are,

$$(39)\quad R_t = -\underset{(11.19)}{20469} - \underset{(1.11)}{13.72}\,(p_{t-1} - p^e_{t-1}) + \underset{(7.47)}{202.1}\,p^e_{t-1} + \underset{(6.90}{0.831}\,s_{t-1}$$

$$+ \underset{(3.20)}{0.03173}\,AGE31\text{-}35 + \underset{(6.54)}{0.0542}\,AGE36\text{-}40$$

$$\bar{R}^2 = 0.930 \qquad D.W. = 1.37$$

$$\hat{\beta} = 0.15$$

The short-run price elasticity is insignificant although negative as anticipated; the elasticity at the mean values of R_t, P_t, and P_t^e is only -0.005. On the other hand, the long-run elasticity with respect to P_t^e is highly significant and positive as expected; at the mean values it is +1.74. Presumably the value of the subsidy is responsible for short-run responses, and this is highly significant; the elasticity of R_t with respect to S_{t-1} at the mean is 0.52. As expected, the age distribution variables show a larger effect on replanting for the older vintages. The coefficient of expectation was found to be only 0.15, suggesting that expected normal prices adjust only

very slowly to fluctuations in current prices. The Durbin-Watson statistic (D.W.) is rather low, but correction for first-order serial correlation did not change the results significantly. 21/

Production

The result of running the regression suggested by equation (37), excluding p_t^e, for 1944-78, yielded

$$Q_t = \underset{(0.24)}{-8617400} + \underset{(4.38)}{0.3295}\, Q_t^* + \underset{(0.97)}{144925E{+}4}\, p_t \underset{(1.90)}{-13982200}\, w_t + \underset{(7.82)}{139822E{+}3}\, t \tag{40}$$

$$\bar{R}^2 = 0.85 \qquad\qquad D.W. = 1.06$$

The coefficient of Q_t^* is significantly different from 1, having a standard error of 0.0752. The probable reason for this low coefficient is the use of an age-yield profile for 1970-79. Yields in this period for all ages must be significantly larger than for earlier periods. This is true for several reasons: there have been technological improvements in the clones themselves; there have been important technological changes in the quality of disembodied inputs; and there has been a continual improvement in the skill of farmers. The result is to weight acreage figures more heavily than should be the case for determination of potential production (see footnote 17). The price effect is not significantly different from zero, but the coefficient has the expected positive sign. The wage rate is significantly negative as expected. The most significant variable is a time trend. If p_t^e were included, it is likely it would only pick up some of this strong trend, emerging with a positive rather than a small negative coefficient. There is also substantial first-order residual correlation. 22/

While (40) is far from a satisfactory result, the regression does illustrate the danger of trying to infer production from the age distribution of trees and the area under cultivation without considerable further disaggregation and taking into account the effects of other variables. The strong and stable technological link betwen the age distribution and production assumed in the WG formulation is clearly not supported by the data for Sri Lanka.

New Planting

As indicated above, we did not expect to obtain good results for this part of our model; we were not disappointed. Equation (38) suggests regressing N_t on Q_t^*, p_t^e and w_t. The result for 1944-78, also including a time trend, is

$$N_t = \underset{(2.12)}{2618} - \underset{(1.22)}{0.314E\text{-}5}\, Q_t^* - \underset{(0.09)}{12727}\, p_t^e + \underset{(0.19)}{219.8}\, w_t - \underset{(0.47)}{50.71}\, t \tag{41}$$

$\bar{R}^2 = 0.05$ D.W. = 1.20

Only the constant term is significant. Prices and wages both have the wrong sign. It is clear that new planting in Sri Lanka, which is a highly insignificant component of total planting in any case, is not explicable in terms of the variables used or the model formulated. The focus on new planting in the WG formulation is clearly inappropriate in Sri Lanka.

Conclusion

Models of perennial supply response that focus on new investment, as does the WG formulation, are not appropriate to the study of a mature industry, such as rubber in Sri Lanka, in which most response to prices and other

factors takes the form of uprooting and replanting existing stands. Our replanting results show significant and positive long-run response of replanting to variations in expected normal prices (elasticity = 1.7); and a small, negative and insignificant response to current prices; and a significant, positive response to subsidies designed to promote replacement of older stands with higher-yielding varieties. The effects of variations in the number of acres planted to older vintages found encourage us to believe the more elaborate formulation, from which our regression was derived, may be worth estimating, but the perverse effects found for the "over-40" category are disturbing. As we suggested above, this effect may well be due to our estimates of area in this category and to the concentration of this acreage in smallholdings.

One of the most significant aspects of rubber supply in Sri Lanka is the steady varietal improvement resulting in higher-yielding trees and a different age-yield profile over time. 23/ This technological improvement provides the impetus for the replanting of older trees, which in turn accounts for most supply response to price in the long run. These changes also make it difficult to infer production from the distribution of trees of different ages. Our harvesting equation, while revealing a strong and significant positive association between potential output in the WG formulation and observed output, also yields a coefficient much less than one. Since new planting is essentially negligible, it is clear that a more complete understanding of supply response based on the uprooting-replanting decision and on the age distribution of the stock of trees at any point in time requires a fuller treatment of the relation between stock and production. The WG formulation,

while useful and appropriate to the derivation of a reduced-form supply function, is clearly greatly oversimplified in the present context. Use of the detailed estate data to develop a dynamic production function for rubber should be the next step in our research on this topic.

Appendix A

Area under Cultivation and Its Components*

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* This appendix is drawn, in part, from a memorandum dated October 24, 1982, from M. J. Hartley to J. Duloy.

An initial attraction of a pilot study on rubber in Sri Lanka was the availability of data on area under cultivation, which contained, in particular, a time-series of age-distributions--a matter of considerable importance to the study of perennials. Subsequent examination of these data, as well as the report of the Rubber Master Plan for Sri Lanka, conducted in 1979 by the Commonwealth Development Corporation (CDC), revealed certain difficulties with these data, which are described in this appendix.

As part of the International Rubber Restriction Agreement of 1934, and in order to assess potential production for its administration reliably, Ceylon (now Sri Lanka) was required to estimate the total area under cultivation and associated yield in a manner that would permit control of total output. Since yields varied with age and type of producer, a massive data collection exercise was conducted to obtain reliable estimates of total area, broken down (marginally) by size of holding [small holders (< 10 acres), small estates (10-100 acres), and large estates (> 100 acres)] and by age of existing stock (by years of planting back to 1922, with a censored "lump" in the distribution for all ages greater than 12 years). In addition, combined two-way breakdowns, by both district and size of holding, were estimated. Finally, estimates of the average yield associated with each size class were calculated, based upon the last three years of actual yield (1929, 1930, and 1931). This provided an estimate of total "assessed standard production," as well as a means of allocating export coupons to all existing registered producers.

The Agreement established a national quota as a given fraction of assessed standard production. Export coupons were then distributed to all

registered producers, with export entitlements determined by the area under cultivation multiplied by the "standard-yield" of the size-class category of the particular producer. Such coupons could be freely traded, and the average monthly market price of coupons (per lb.) has been collected from the inception of the coupon-rationing scheme in June 1934 until its suspension in May 1942. The fact that export coupons required registration provided an overriding incentive to comply with the spirit of the law. Attempts were made, at the time, to monitor and spot-check declared registered areas and reported yields, given the economic incentive to over report. Penalties were severe for gross misreporting and noncompliance. In short, the "base-line" (1934) area and age-distribution data are likely to be as reliable as can be expected.

From 1934 on, the International Agreement also provided for a total ban on all new planting and for replanting of existing areas only upon receipt of an "application to replant," which was subsequently approved by the Rubber Controller. (Indeed, the control of all new planting and replanting, through government permits, still exists even though the restriction scheme has expired.) Violations were prosecuted, the penalty being the uprooting of all discovered unapproved planting. In short, the entire sequence of annual data on areas subject to new planting and replanting since 1934 is extremely reliable and represents the basis for the official estimates of subsequent areas under cultivation and its associated breakdowns by age, size of holding and revenue district. Finally, we note that no significant rubber areas were planted with high-yielding clonal material prior to 1934, whereas all approved new planting and replanting since 1934 has been, by law, restricted to high-

yielding varieties. (The sequence of new planting and replanting since 1934 provides a basis to estimate the age-distribution of high-yielding varieties and the original unselected seedling stock, separately, although we make no use of this possibility.)

The official statistics in the sequence of Annual Reports of the Rubber Controller (ARRC) since 1934 provide annual estimates of the so-called "registered areas" separately for replanting and new planting, each broken down by a joint three-way classification into revenue district, size-class, and type of planting material (unselected seedling versus budded high-yielding varieties). Hence, from these data, the sequence of gross additions to the total area (new planting) can be added to the previous year's area in each category. Replanting represents a change in area composition by age without changing total area. The official statistics assume that the areas uprooted for replanting always come from the seedling (older, low-yielding) varieties and are removed in order of age priority, with the oldest stock removed first. While this assumption may not correspond to reality, in the absence of records indicating which specific vintages were removed, it is a plausible approximation.24/ The major problem with the post-1934 area data, however, is that no systematic records of gross removals from the existing stock in each year were maintained. Such removals would be through abandonment of existing rubber stands or diversification to alternative crops. Thus, to the extent that any unreported removals of areas formerly under rubber cultivation occurred, the official registered area series will be biased upward. Further, since this effect is cumulative, the magnitude of the upward bias increases over time.

The severity of this problem first becomes apparent in 1946, when an independent Census of Agriculture (see column (5) of Table 1) indicated that, exclusive of holdings of less than 1 acre in size, Ceylon had 574,522 acres of rubber under cultivation, compared with an official registered area (column (4)) of 659,533 acres. It may be possible that the difference of 85,031 acres could be attributed to the missing smallholdings (< 1 acre) in the 1946 Census, since the size distribution of the 146,077 acres of total small holdings (< 10 acres) was not known precisely, and the average small holding in that year was officially estimated at 1.46 acres (ARRC, 1946). A second independent estimate was obtained for 1951, with the publication of the Census of Agriculture of 1952. It estimated a total of 337,374 acres under cultivation in Ceylon (column (6) of Table 1)--a figure that excludes holdings of less than 20 acres. The registered area in that year (column (7)) indicated a total of 655,501 acres under cultivation, of which 343,244 were on large estates (> 100 acres) and 140,715 were on small estates (10-100 acres), accounting for 483,959 acres. The excess in officially registered area of 146,585 acres in 1946 could represent the total area in holdings between 10 and 20 acres that were missing from the 1952 Census taxonomy, since the average official holding in the 10-100 acre category was reportedly only 25.34 acres (ARRC, 1951). A third reference point was based upon the 1962 Agricultural Census (column (9)) as reported in the ARRC. (We have been unable to locate the 1962 Agricultural Census.) The Rubber Master Plan (RMP) reports a total of 566,639 acres in 1962, however, whereas the official registered area (column (10)) is 674,274 acres. This difference of 107,635 acres is the first estimate available that was not obscured by differences in the reported taxonomy or missing holdings in particular size groups. A final comparison is

Table 1: ESTIMATES OF ACREAGE UNDER RUBBER CULTIVATION (SELECTED BENCHMARK YEARS):

Revenue District:	(1) 1921	(2) 1921	(3) 1934	(4) 1946	(5) 1946	(6) 1951	(7) 1951	(8) 1951	(9) 1962	(10) 1962	(11) 1979	(12) 1979	(13) 1979
Colombo	27,898	36,917	52,201	55,890	51,158	23,212	61,760	32,510	63,675	66,260	66,919	63,570	77,558
Kalutara	82,270	95,113	114,562	120,532	108,176	62,747	123,969	84,162	125,999	128,123	126,103	125,227	104,728
Kandy	33,636	40,790	48,680	48,371	35,777	18,204	49,614	35,480	17,073	45,886	42,342	16,207	8,398
Matale	28,477	31,048	35,876	35,690	32,098	20,178	35,256	30,018	20,632	34,952	29,982	19,836	6,916
Nuwara Eliya	637	640	665	665	463	120	664	619	183	304	656	183	-
Galle	34,603	48,126	63,933	71,539	58,962	34,237	72,158	51,265	57,869	75,436	73,193	55,527	38,779
Matara	11,493	14,773	22,347	26,822	23,743	11,673	26,937	21,072	23,447	29,097	28,115	22,470	18,772
Hambantota	-	60	260	260	217	125	248	175	218	242	228	224	-
Trincomalee	80	-	-	-	-	-	-	-	-	-	-	-	-
Kurunegala	13,793	14,559	17,849	18,260	17,484	12,838	12,195	16,621	15,494	18,675	17,501	14,883	14,573
Chilaw	33	51	60	60	18	7	69	32	130	77	77	128	-
Badulla	16,647	16,707	21,286	21,302	20,576	14,548	20,713	20,439	8,569	19,916	19,449	15,970	-
Ratnapura	52,978	58,603	92,080	97,274	93,274	57,082	98,984	79,841	96,235	104,660	102,758	96,747	94,107
Kegalle	87,570	104,054	134,218	138,586	132,576	82,403	146,445	111,715	129,143	150,626	144,217	128,967	151,658
Moneragala	-	-	-	-	-	-	-	-	7,972	-	-	-	-
Ceylon Total:	390,115	461,441	604,111	659,553	574,522	337,374	635,501	483,959	566,639	674,274	651,540	559,939	513,489

DEFINITIONS AND SOURCES

(1) Total Area, Census of Production, 1921
(2) Total Area, Rubber Control Dept. Estimates in 1934 for "Prior to 1922"
(3) Total Area, Rubber Control Dept., 1934
(4) Total Area, Rubber Control Dept., 1946
(5) Total Area of Holdings above 1 acre, Census of Agriculture, 1946
(6) Total Area of Holdings above 20 acres, Census of Agriculture, 1952
(7) Total Area, Rubber Control Dept., 1951
(8) Total Area of Holdings above 10 acres, Rubber Control Dept. 1951
(9) Total Area of Holdings above 20 acres, Census of Agriculture, 1962
(10) Total Registered Area, Rubber Control Dept., 1962
(11) Total Registered Area, Rubber Control Dept., 1979
(12) Total Actual Area, Rubber Control Dept., 1979
(13) Total Area, Rubber Master Plan, 1979

afforded by a detailed aerial photography survey, followed up by a stratified random sampling of particular areas identified as being under rubber to confirm the photographic evidence. This was conducted by the RMP in 1979 (column (13)), where a total of only 515,489 acres is estimatd as under rubber. This compares with the official registered figure (column (11)) of 651,540 acres for 1979, or a difference of 136,051 acres.

In addition, since 1962 and as a result of the unequivocal evidence provided by the Agricultural Census of that year, the Rubber Control Department provides "revised" estimates of area under cultivation (broken down by both district and size of holding since 1968), which it terms "actual areas under rubber." The revised RCD estimate for actual total area in 1962 was 567,320 acres, 106,954 acres less than the estimate provided by registered areas and almost identical to the Census estimate (a difference of only 681 acres). However, the official estimate for 1979 (column (12)) is 559,939 acres, which still differs from the RMP figure by 44,450 acres. The RMP estimate for 1979 appears to be the best estimate.

In sum, between 1934 and 1979 roughly 136,000 acres disappeared from the officially registered area rolls through unreported abandonment and/or diversification to alternative crops. Of this difference, the Rubber Control Department officially acknowledges 91,601 acres, or about two-thirds of the discrepancy. If one believes the sequence of Census and RMP estimates, one can determine the range of years over which the various removals must have occured and then allocate these to the individual years, making use of such knowledge as the price of rubber (e.g., rubber trees are more likely to be removed during periods of low prices), the institutions and legislation in

effect (e.g., if a severe quota restrictions of 60% of assessed standard production is in effect (as in 1936), removal is more likely), etc. Further, various discussions with knowledgeable sources in Sri Lanka suggest that the discrepancies are mostly due to small-holder abandonments in the higher elevation regions, where yields are lower. 25/ Finally, removals are more likely among older vintages of low-yielding seedling varieties. In short, plausible assumptions can be advanced to allocate the discrepancy between the registered and true areas under cultivation across years, vintages, types of planting material, revenue districts, and size of holdings to obtain revised estimates at the same level of disaggregation as the official registration data.

In our statistical analyses (reported in the text), we make use of both the official area statistics and a revised series in which the discrepancy has been allocated across vintages only in accordance with the rules discussed below. The sensitivity of our parameter estimates to use of these two alternative series is slight.

Details of Age and Vintage Corrections

In constructing the revised acreage and vintage data, we have used only two benchmarks - the Agricultural Census of 1962 and the Rubber Master Plan Inventory Survey, 1977/78 (the 1977/78 figure was used as the total acreage figure for 1977). The other available benchmarks were not used, because all rubber acreage was not included; the Agricultural Censuses of 1946 and 1951 were only for holdings above 1 acre and above 20 acres, respectively. As shown in Appendix Table 2, the 1962 Census of Agriculture records

Appendix Table 2: REVISED ACREAGE ESTIMATES (1934-78)

	Official registered acreage	Benchmark estimates	Acreage corrections	Revised acreage estimate
1934	605,132	-	-	605,132
1935	605,893	-	-	605,893
1936	587,889	-	-	587,889
1937	589,382	-	-	589,382
1938	594,724	-	-	594,724
1939	610,225	-	-	610,225
1940	638,274	-	-	638,274
1941	637,632	-	-	637,632
1942	637,560	-	-	637,560
1943	657,289	-	-	657,289
1944	657,532	-	-	657,532
1945	659,803	-	-	659,803
1946	659,553	-	-11,960	647,593
1947	658,983	-	-11,960	635,063
1948	658,349	-	-11,960	622,469
1949	655,108	-	-11,960	607,268
1950	655,225	-	-	607,385
1951	655,501	-	-	607,661
1952	656,879	-	-11,960	597,071
1953	657,427	-	-11,960	585,659
1954	659,209	-	-11,960	575,481
1955	660,985	-	-11,960	565,297
1956	659,247	-	-11,960	551,599
1957	660,725	-	-	553,077
1958	664,836	-	-	557,188
1959	668,178	-	-	560,530
1960	668,948	-	-	561,300
1961	670,830	-	-	563,182
1962	674,274	566,639 /a	-	566,639
1963	675,683	-	-1,564	566,484
1964	669,179	-	-1,562	558,416
1965	671,487	-	-1,564	559,160
1966	672,592	-	-1,564	558,701
1967	673,378	-	-1,564	557,923
1968	674,539	-	-1,564	557,520
1969	673,515	-	-1,564	554,932
1970	674,365	-	-1,564	554 218
1971	673,819	-	-1,564	552,108
1972	675,763	-	-1,564	552,488
1973	655,920	-	-1,564	531,081
1974	653,401	-	-1,564	526,998
1975	652,802	-	-1,564	524,835
1976	652,179	-	-1,567	522,648
1977	651,157	520,059 /b	-	520,059
1978	650,849	-	-	519,751

/a Census of Agriculture, 1962, Volume II: Land Utilization.
/b Rubber Master Plan, 1977/78 Inventory Survey.

566,639 acres of rubber; therefore 107,635 acres of registered rubber had been either abandoned or diversified into other crops by 1962. In discussions with officials of the Rubber Control Department, we learned that, in the early years of rubber planting, a large amount of seedling rubber had been planted on higher elevations, as a substitute for coffee which was destroyed by a blight in the late 1800s. However, rubber is a low elevation crop which does not grow well on higher elevations. As the planters became more familiar with it, planting on these higher elevations ceased. However, since Ceylon was the primary rubber producer for the allies during World War II (Malaysia, Indonesia, and Thailand were occupied by the Japanese), it was illegal to remove rubber during this period. Also, it is unlikely that any rubber acreage was abandoned because of the high prices resulting from its scarcity (see Figure 3). Therefore, the majority of these acres must have been removed in the postwar period. We decided to allocate the acreage abandoned and the acreage diversified into other crops to the 1946-56 period. With the exception of 1950-51, this was also a period of relatively low prices. As shown in Table 2, we removed this acreage evenly in the years 1946-49 and 1952-56 (11,960 acres per annum). These corrections to the official rubber statistics yielded 566,639 acres.

Our second acreage benchmark, the Rubber Master Plan's aerial and inventory surveys, identified 520,059 acres in 1977. Since this is a period of steadily rising prices, we did not identify any specific years in which removals or abandonments were more likely. Therefore, we revised the acreage series evenly throughout the period removing 1,564 acres per year. The

resulting acreage series, as shown in Table 2, is our revised area estimates for the period 1934-78.

For the construction of the vintage series, we used the official statistics published in the ARRC, (see Appendix Table 1, "Rubber Acreage in Sri Lanka According to the Year of Planting"). However, two problems arose:

(a) allocation of the "acreage planted prior to 1922", the so-called "lump" (see Appendix Table 1); and

(b) how to reflect our revisions of the official acreage series, as outlined above.

For the allocation of (a) above, we used estimates of rubber acreage provided by Snodgrass (1966) (see Appendix Table 3). Snodgrass constructs a rubber acreage series back to the year of first planting, 1900. 26/ We have smoothed these data during 1911-15 to reflect a steady expansion of acreage through new planting; as outlined above, this is only an approximation and ignores any removals or abandonment that may have occurred in this period. This produced a "smoothed" acreage series (Appendix Table 3, column 2), and from that series, we constructed the sequence of annual new plantings (column 3). The annual new plantings were used to generate the percentage of total acreage in 1921 (column 4), that was planted during 1900-21. The allocation of the lump was achieved by multiplying the "acreage planted prior to 1922" by these percentages; this completed the age distribution of 1934 acreage by year of planting.

The complete age distribution for 1934 was updated through 1978 by using the official statistics on new planting, removals, and replanting.

Appendix Table 3: RUBBER ACREAGE AND NEW PLANTING ESTIMATES (1900-21)

	(1) Snodgrass estimates /a	(2) Smoothed series	(3) New planting /c	(4) New planting as % of 1921 acreage
1900	1,729.7	1,729.7	1,729.7	0.44
1901	2,693.4	2,693.4	963.7	0.27
1902	4,200.7	4,200.7	1,507.3	0.39
1903	11,613.7	11,613.7	7,413.0	1.90
1904	13,096.3	13,096.3	1,482.6	0.38
1905	35,829.5	35,829.5	22,733.2	5.83
1906	50,408.4	50,408.4	14,579.0	3.74
1907	100,816.8	100,816.8	50,408.4	12.92
1908	131,704.3	131,704.3	30,887.5	7.92
1909	154,437.5	154,437.5	22,733.2	5.83
1910	186,560.5	186,560.5	32,123.0	8.23
1911	184,583.7	188,932.7/b	2,372.2	6.08
1912	222,637.1	191,329.5/b	2,396.8	6.14
1913	232,768.3	193,751.1/b	2,421.6	6.21
1914	168,275.1	196,222.1/b	2,471.0	6.33
1915	198,668.4	198,668.4/b	2,446.3	6.27
1916	221,648.7	221,648.7	22,980.3	5.89
1917	229,308.8	229,308.8	7,660.0	1.96
1918	259,455.0	259,455.0	30,146.2	7.73
1919	308,627.9	308,627.9	49,172.9	12.60
1920	347,027.0	347,207.0	38,399.1	9.84
1921	390,170.9	390,170.9	43,143.0	11.06

/a Snodgrass (1966).
/b Smoothed estimates.
/c $NP_t = A_t - A_{t-1}$.

Since throughout this period all plantings and removals were closely monitored, these statistics are considered extremely reliable. In reconciling the official age distributions with our revised acreage series, we adjusted according to the rule "oldest out first," but we removed all old seedling acreage prior to removing high-yielding acreage. In reconciling these official age distributions with our revised acreage series, we also used the same rule. After making these two corrections to the official data, we had a time series of acreage and vintage data.

Appendix B

Other Data Available for Analysis of Rubber Supply Response in Sri Lanka*

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* The appendix is drawn from a memorandum dated October 24, 1982, from M. J. Hartley to J. Duloy.

The Production Data. Reliable monthly data on total production of all major grades of processed rubber are available back to 1934. During the period of the International Rubber Restriction Agreement, 1934-43, the official production data represent the quota limit assigned to Sri Lanka, based upon a mandated, but varying proportion of the estimated potential production for each separate year. Over this period, since the quota was not met in some years and the shortfall carried-over to subsequent years, the data on total exports (available monthly) provide an extremely reliable measure of actual production, as local consumption was negligible. From 1943 on, monthly total production data are available, and, from 1951 on, these data are disaggregated by the six major grades of processed rubber.

The major problem is that virtually no information is available on production by size-of-holding or by type-of-planting material to enable a reliable comparison of the production functions of smallholdings versus estates or yields of seedling versus high-yielding varieties. The official statistics provide a monthly breakdown of smallholder sheet production only from 1950 to 1958, and inquiries indicated that this grade encompasses virtually all of smallholder production. Since the registered area under cultivation is disaggregated by size-of-holding for the entire sample period (from 1934 on), this "gap" in the data base is regrettable. We shall, however, endeavor to make use of information contained in a cross-section survey of smallholders in two districts (Kalutara and Ratnapura), conducted by the (then) Ministry of Plantation Industries (in connection with a Bank Smallholder Rubber Rehabilitation Project) in 1978. To this end we have succeeded in relocating the original individual response forms and have recoded, punched

and edited these data for possible use. As is often the case, the questionnaire was designed for another purpose, and is of limited use in the present study. Further, the absence of systematic record-keeping on the part of most smallholders makes even these data of dubious reliability. Another survey of rubber smallholdings, conducted by the Ministry of Plantation Industries in 1971/72 also contains useful tabulations, but attempts to locate the original responses failed.

Exports, Stocks of Inventories and Local Consumption. Monthly data on total exports is available from June, 1934 to December 1979. From 1951 on, these data are disaggregated by the six major grades. Since duties are only levied on exports, and since the dealers and other export traders maintain stocks of inventories prior to export (which fluctuate with currently prevailing and expectations of future prices in both the Colombo and London auction markets), there is a logical economic basis for the departure between the timing of production and export. Indeed, presuming rational behavior on the part of the holders of stocks of processed rubber, modelling such behavior should reveal information as to what prices were expected in the two auction markets.

To this end we have also collected data on the monthly stocks of inventories held by various agents from 1935 to 1979. Total stocks are available over the entire sample period and, except for a few gaps, are disaggregated by type of agent (viz., at customs; with dealers and shippers; on estates by size-class; and at manufacturers). In addition, over the period from 1934 to 1951, legislation restricted the maximum stock position which may be maintained by both dealers and large estates, and these legislated maxima

have also been collected, along with a legislative survey of such regulations. To eliminate the portion of crop on which no export duties are levied, we have collected an annual series on local consumption from 1934 to 1979.

Rubber Price Data. Monthly data on the Colombo auction price of two of the principle grades of rubber - Ribbed Smoked Sheet No. 1 (RRS #1) and Latex Crepe #1 - are available from 1927 to 1979. In addition, from 1913 to 1979 we have obtained annual data on the implicit export price of all grades of rubber, combined - extracted from value and volume data of customs returns - and, since 1955, the implicit export price of the six grade categories. The Colombo auction price is net of all export duties, transport, freight and insurance charges, and brokers fees, and thus represents the producer price. We also have obtained an annual time-series of the f.o.b. price of RSS #1 from 1934 to 1979, with monthly breakdowns from 1962 on. The f.o.b. price represents the London auction price, net of freight, insurance and other such charges. In the case of monthly f.o.b. price data, it is based on the average of the four previous-week prices for the month. Since the f.o.b. price reflects the effect of the exchange-rate changes, arising through devaluation of the Sri Lankan rupee the SLR/UK and SLR/US$ official exchange rates (back to 1933) have been compiled. Finally, we have collected the monthly prices for export coupons over the period when the International Rubber Agreements was operative.

Cost of Production. Unit costs of production are useful for two related purposes within the context of a system of input demand and output supply equations. First, the difference between the producer price and unit cost of production define the profit margin. Second, in cases where it is not

possible to obtain data on the prices and/or quantities of all relevant variable inputs - a situation which is typical - the specification of a production function and/or system of input demand/output supply functions, using only the incomplete set of observed input levels and prices will result in a specification bias. The additional use of the cost of production data in such a system provides an identity containing information on the total expenditure on the unobserved inputs, or an independent check on the reliability of the data in a "complete data" situation.

In the present case we have obtained data on the unit costs of production for estates only. No systematic time-series data on smallholder costs is available - though these would inevitably require the use of an implicit market wage rate for the use of unpaid family labor. We have exploited four separate sources to try to establish an estate total c.o.p. time-series, with the result that the years 1910, 1913, 1918, 1920, 1921, 1925, 1929-32, 1939-46, 1952-54 and 1957-1979 are covered. The data for 1957-79 are based upon a regular annual survey of estates conducted by the Department of Statistics, GOSL; whilst other data are obtained from less-formal procedures. In addition, the 1957-79 data are disaggregated by various expenditure categories (salaries; labor wages; maternity, medical, feeding and schooling; insurance and rent; pest control and fertilizer; and other expenditures). We are indebted to Mr. Marshall Perrera of the RCD for making the most recent data available to us. These breakdowns are extremely useful, as they provide an estimate of estate employment (wages are known), and an independent check on the fertilizer prices and quantities (see below) over that time-span.

Inputs and Input Prices. Obtaining reliable data on the levels and prices of variable inputs has proven to be extremely difficult. Indeed, it should be stressed, in the context of the dynamic vintage production function which distinguishes separate age-classes, even with complete aggregated data there is still the remaining problem of allocating these input levels to age clases in a manner consistent with profit maximizing behavior, given the prevailing age-distribution of area under cultivation in any year. This problem is analogous to the problem of allocating the observed levels of aggregate area-replanted in a particular year to the particular collection of vintages uprooted in the preceding year - required in order to endogenize the determination of the age-distribution from one year to the next.

Employment, Wages and Other Aspects of the Labor Market. There is no time-series on the total employment in the aggregate rubber sector, or, indeed, even in the rubber estate sector (i.e., neglecting smallholdings). The most relevant series is total employment on estates employing Indian labor, including not only rubber, but also tea, coconut, cardamons and cocoa - available from 1933 to 1978. The labor force on the plantation sector in Ceylon was (originally and currently) drawn largely from imported Indian Tamil workers. Insofar as the British colonial government at the time maintained records on the number of such workers, as well as its total population in Ceylon, estimates were regularly made and published. However, the reliability of these data is questionable. In addition, for our purposes, there is the problem of disaggregation to the portion employed on rubber estates. The total employment in the entire estate sector is disaggregated into Ceylonese and Indian nationals from 1942 on. In addition, from 1971 to 1973 we have

collected the total employment specific to the rubber (and tea) sectors. One approach might be to assume a fixed relationship between area under cultivation and total employment - as a possible a priori method of disaggregation. This approach suffers from the lack of systematic time series - except at discrete benchmarks associated with Agricultural Census data - on area-under-cultivation in coconuts, cardamons and cocoa. Further, such a fixed relationship between area and employment defeats the purpose of analyzing changes in the labor-per-acre utilized in response to changing wages and prices.

We have compiled a monthly time series of an index of minimum wages payable to workers in the rubber and tea sectors from 1939 to 1964 - these having been established by government legislation. This series may be "spliced" with a monthly series on an agricultural wage index from 1965 to the present. In addition, we have collected an annual time series on the average daily wage rate for workers in rubber growing and manufacturing (disaggregated by male and female adults, as well as children) from 1945 to 1979. Auxilliary data on wage rates prevailing in other sectors of the economy - various forms of manual unskilled occupations - have also been obtained, as measures of the opportunity cost of alternative forms of employment. In addition, data on the average number of hours worked per month has been collected (on a biannual basis from 1964 to 1971) for male, female and child rubber-sector workers - as an indicator of total earnings, when combined with average daily wage rates. These can be matched with the labor wage component of the unit cost of production.

As a further indicator of labor market conditions, we have collected time-series for the entire plantation sector from 1934 to 1979 on the number

of strikes, the number of workers involved, man-days lost via strikes and the number of strikes on which the data were reported. Also, as an indicator of the availability of labor we have collected a time-series on the number of workers registered for employment or better employment among unskilled, semi-skilled occupations, spanning the years 1938 to 1971 (with totals available there-after). A "highly unreliable" series on total unemployment from 1933 to 1979 (with occasional gaps) has also been obtained. Of similar alleged quality is the unemployment rate - available, assortedly, from 1946 to 1979.

Fertilizer Use and Fertilizer Prices. The key materials input involved in explaining secular changes in yields is fertilizer. Unfortunately, these data pose similar problems. A special fertilizer study, conducted by a German consultant group, to assess fertilizer use by agricultural sector in Sri Lanka was obtained. This provided estimates of the total tonnage by principal source of nutrient (sulphate of ammonia, urea, rock phosphate and super phosphate, muriate of potash and other fertilizer) applied to rubber (as well as separate estimates for tea, rice, coconuts and other crops). However, the data are only available from 1962 to 1979. Discussions in Sri Lanka with the resident German representative of the consultant group, Dr. Udo Volz, who was in charge of the study, also indicated the difficulty of extracting relevant data and its questionable reliability.

Since almost all of the fertilizer utilized in Sri Lanka is imported - the exception being the recent attempts to establish urea plants as a locally-produced source of nitrogen, we decided to conduct an intensive investigation of the sequence of historical customs records to extract the value and volume data of all imported sources of nitrogen (N), phosphorous (P)

and potassium (K). An exhaustive list of more than twenty-five ingredients was compiled, and the value/volume data for every year from 1925 to 1968 was collected. The nutrient composition (N, P, or K) by weight of every source or ingredient was then compiled. The implicit import prices were then weighted by nutrient-composition-weights to obtain price and quantity indices for N, P and K, separately, for the complete time span. We have therefore have a lengthy, highly reliable import price series for fertilizer nutrients. The corresponding quantity series, however, applies to all agricultural sectors, and not just rubber (or tea). The problem of how best to disaggregate the total fertilizer nutrient measures to rubber (and tea) remains. Historical accounts (Snodgrass (1966) and Forrest (1967)), as well as an FAO fertilizer study (1965), indicate some useful qualitative information. Apparently, with respect to rubber and tea, the latter sector was the principal user of fertilizer over the span from 1933 to the early 1950s, when the rubber sector began intensive fertilizer use (in connection with the government-subsidized rubber replanting scheme (1953 to the present)). Thus, it would not be correct to assume that the proportionate allocation by sector, manifest in the data of the German fertilizer study, would be applicable to rubber (or tea) prior to 1962. Further, smallholder use of fertilizer prior to 1958 was alleged to be negligible, despite official recommendations to the contrary. Resolution of this problem via statistical means therefore remains as an issue.

Other Inputs. Cost of production breakdowns indicate that, apart from imported capital equipment involved in the manufacturing of rubber, labor

and fertilizer account for the vast bulk of all expenditures. This is fortunate since, apart from pesticides (which we elected not to attempt to treat analogously to fertilizer), we were unable to locate any relevant data on prices or quantities. Finally, we note that, if a general price deflator is required to express prices in real terms, we have "spliced together" an annual consumer price index from various sources from 1934 to 1979. Further, from 1938 to 1979, we have also obtained the separate components of the CPI (food; fuel; and light; rent; clothing; and miscellaneous).

Weather Data. The varied effect of total rainfall, and its alternative measure, the total number of rainy days, on rubber yields is important to the study of rubber supply. The inverse relationships between the amount of rainfall and rubber yields - rain interferes with tapping - has been noted by Barlow (1978) and documented with Malaysian data. In addition, temperature and relative humidity are alleged to be correlates of the occurrence of various types of disease and pest infestations, with an obvious indirect effect on yield trajectories and stand densitis. Since climatic conditions exhibit considerable regional variation within Sri Lanka, it is of some importance to attempt to quantify the effect of weather conditions upon current and future yields. Despite the fact that these factors are exogenous events, they may be of importance in explaining historical changes in land-use patterns and in guiding such choices currently and in the future. Furthermore, being able to account for the proportions of variation in yields attributable to weather is important in assessing the overall goodness of fit of the complete model. Finally, if we are able to quantify the complete probability distribution of weather events, it will provide an explicit quantitative means

by which the two principal sources of risk - the other major source being uncertain fluctuations in world market price - may be treated.

For these reasons the discovery of extensive historical weather records at the GOSL Department of Meteorology was considered important to the project. From those archives we have obtained monthly time series data from 1933 to 1979 on (a) the number of inches of rainfall; and (b) the number of days per month of recorded precipitation from a set of forty-nine weather recording stations within the rubber (and tea) producing regions. For each such region, our coverage contains between three and six stations per region. In addition, we have collected monthly data on the maximum and minimum temperature for twelve relevant locations for the same years, as well as the monthly relative temperature for twelve relevant locations for the same years, as well as the monthly relative humidity. These data should provide a very reliable estimate of the probability distribution of each type of weather index by region. Thus, for purposes of studying the effect of our weather indices on current and future yield, we are forced to aggregate these to national indices. We propose to utilize the area under rubber cultivation in each region as weights to aggregate weather across regions. Here, the fact that the official statistics on area under cultivation are flawed (see Appendix A) created an additional statistical problem to be resolved.

Other Miscellaneous Data. The principal source of government revenue extracted from the rubber (and tea) sectors is obtained from export duties and cesses. Since 1934, Ceylon has imposed a variety of specific cesses per lb. exported - each earmarked for a different purpose. We have extracted the cess-rates (per lb.) for medical aid; research and propaganda; administration

of the Rubber Control Department; and the rubber replanting cess (since 1953), separately. In addition, since 1950, a so-called sliding-scale for determining export duty rates was imposed. The rates applicable to every grade of rubber have been collected and the "trigger-mechanisms," whereby the rate structure changes with the prevailing Colombo auction price, have been recorded. Further, the total amount of cess-collections (since 1934) and the total amount of export duty collected (only given from 1962 on have been recorded. This should permit a careful analysis of the public finance aspects of the problem - including the possibility (via simulation of an estimated output-supply/input-demand model) of analyzing the issue of optimal taxation relative to a posited objective - e.g., maximize government revenues. The fact that the estate sector (all holdings of greater than 50 acres) was nationalized between 1972 and 1975 (and accounts for roughly 2/3 of the area under cultivation) implies, however, that such matters may be somewhat moot since 1975.

The major policy intervention, not yet discussed in detail is the Rubber Replanting Subsidy Scheme, introduced in 1953. At that time, in part due to the prior quota restrictions, in part due to the need for maximum production to support the Allies during WWII, and in part due to the boom in prices during the Korean War, Sri Lanka's rubber stock was both overaged and contained a minimal proportion of high-yielding clonal varieties. In response, Ceylon initiated a Rubber Replanting Subsidy Scheme, which provided specified subsidy grants (per acre replanted) at yearly intervals over the six years of gestation, with specific guidelines as to cultivation practices to be followed to qualify for each successive payment. It was intended that the

total of all subsidy payments would cover roughly 50% of total replanting costs. Applications for replanting permits under the Scheme were screened as to suitability of the land for rubber, and the subsidy rate structure was progressively revised upwards to account for inflationary trends in the cost of replanting. Fertilizer dosages were specified for each year from planting and government fertilizer distribution centers were established, along with government extension service agents to advise on "proper" cultivation practices for the new varieties.

We have collected data on the progress of the subsidy rate structure since 1953, as well as detailed information of its effect on replanting. Breakdowns on acreage replanted each year, jointly by size-of-holding and district, are readily available from the ARRC. Since 1958, the number of applications to replant has been recorded and, from 1969, it is broken down by size-of-holding. In addition, since 1953, the total income to and expenditure from the Rubber Replanting Fund and the total of annual subsidy payments made have been assembled, as well as the specific sources of income and the breakdown of expenditures made (subsidies, nurseries, fertilizers, extension service agent fees, etc.). These data should permit a careful assessment of: the financing and impact of the Scheme; estimates of the elasticity of replanting response to subsidy levels; and, analysis of "optimal" subsidy levels.

A major problem, as noted earier, is that of identifying the age of areas uprooted for replanting. To this end, we have obtained a probability distribution of the age of acres "intended for removal" from the Rubber Master Plan survey of 1979. This is better than no data, but obviously depends upon

the age distribution prevailing in 1979, as well as the prevailing price structure, etc.

As a final note, we have attempted to compile a chronological account of all legislation applicable to the rubber sector, as well as assorted historical qualitative information - such as the virtual impossibility of obtaining certain fertilizer imports during WWII - to aid the eventual model construction and account for the behavioral consequences of structural changes.

FOOTNOTES

1/ Since even new plantings usually replace an existing crop, current prices of rubber must be considered not only in relation to rubber prices in the more distant future but also in relation to the prices of the crops now occupying the land and utilizing other resources, now, in the interim gestation period, and finally when rubber planted now begins to yield. The difference is that the opportunity costs of replanting are directly related to whatever factors are affecting current rubber prices. Since the alternatives to a newly planted crop are generally much more diffuse, very little significant response to prices of alternative crops has been found even in conventional supply response studies for annual crops. Replanting decisions are much more sharply focused. Moreover, such decisions are likely to be quantitatively much more important in the case of a mature industry, in which most highly suitable land is fully exploited, than for a nascent and rapidly expanding industry.

2/ This is probably more nearly the case for coffee than for rubber. In the case of rubber, the current rate of tapping affects the output obtainable in later years. Indeed, when replacement of a stand of rubber trees is contemplated, the trees are often tapped at increasing intensities in an effort to extract the maximum latex obtainable over the remaining life of the tree.

3/ If all potential output is not always harvested, a discontinuity in the derivative of output with respect to prices is introduced (see Nerlove, 1979, p.882). Such a discontinuity implies that neither exact nor approximate certainty equivalents for unknown future prices exist (see Malinvaud, 1969). Supply response cannot then be derived as the solution to a dynamic optimization problem in which uncertain future prices or other variables are replaced by their conditional expectations given past experience (so-called quasi-rational expectations; see Nerlove, Grether, Carvalho, 1979, p.306).

4/ "Maximum output" is used in the figurative sense; Q_i^* is not a maximum in the prodution function sense. In fact as used in a later section of this paper, Q_i^* represents the average age-yield profile. Actual output could be above or below it, therefore it could not be a "true maximum."

5/ We have also adopted this simplification in our initial analysis, although the longitudinal data on estates will make possible an analysis of how technological change and other inputs affect the age-yield profiles. Estimates of the age-yield profiles are obtained in our case from these estate statistics.

6/ It is interesting to note that Nerlove (1956, 1979) is very explicit about the assumption that P_t^* in (2) is an expectation of "normal" price, i.e., the price expected to prevail "on the average" in <u>all</u> future periods. In contrast, WG in (7) assume nothing about how the

expectations p_t^e are formed; implicitly they differ depending on which period in the future the subscript refers to. When (7) is used to derive a function representing expected discounted net future revenue from a tree, however, static price expectations (i.e., expectations, however formed, which are the same for all future periods) are implicitly assumed. It can be shown (Nerlove, 1972) that static expectations are necessary in order to make meaningful the concept of a long-run equilibrium level towards which economic agents may be assumed to move and thus to justify a partial adjustment model of the type implied by equation (1).

7/ WG assume acreage will be be fully harvested. See footnote 2. If this were not the case, in general the uncertain future prices which enter the discounted net revenue function could not be replaced by single-valued expectations.

8/ The reason for this assumption is not made clear. One would think that the decision depends entirely on current price in relation to current harvesting costs.

9/ Refitting the model omitting Q_{t-2}, using current rather than lagged price, and including a trend term yields (similar to Grilli et al (1981))

$$Q_t = \underset{(2.24)}{28{,}199.0} + \underset{(4.86)}{0.66}\, Q_{t-1} - \underset{(0.02)}{88.2}\, p_t + \underset{(2.35)}{787.4}t,$$

$$\bar{R}^2 = 0.876 \qquad D.W. = 2.32$$

which suggests no response to price at all, but cannot then be interpreted in terms of the standard Nerlovian formulation. The explanation of current output is entirely determined by last year's output and a trend, which presumably represents technical progress.

10/ There are some rather serious problems with the official area statistics which are discussed in Appendix A to the paper.

11/ This neglects the problem of seedling vs. high-yielding varieties, as well as major differences within each of these groups, and their separate areas, age distributions, and age yield profiles in the determination of the results.

12/ We ignore for the moment that areas to be replanted require a minimum of one year to complete uprooting and clearing before replanting may occur. This also ignores the existence of alternative crops, since

some uprooting may result in crop diversification and not rubber replanting. Moreover, during the years of immaturity there are extensive maintenance expenditures which we take into account only through the wage rate.

13/ The revenues obtainable from nonagricultural employment and from alternative crops, are also important, but difficult to specify, and to estimate due to a lack of data.

14/ We can imagine the relationship to be derived by an explicit dynamic optimization procedure in the manner of WG provided we also assume, as they do, that all potential output from a stand will always be harvested.

15 However, the model is not closed, since F_{t+1} is not determined. This means that for prediction beyond the sample a rule of "oldest out first" must be adopted.

16/ One of these varietal improvements is the lowering of the age at which significant yield may be obtained. This could be expected to enhance, ceteris paribus, the desirability of up-rooting and replanting any given stand. Some of this improvement is also due to better agronomic practice.

17/ These are taken to be the unsmoothed values from Figure 5 except that the first six values have been set to zero. This yield curve, which

has been drawn from our estate sample over the period 1970-79, would not be appropriate for all Sri Lankan producers nor for all time periods. In fact, Colin Barlow has suggested the existence of three distinct age-yield profiles: (i) pre-war high yielding; (ii) post-war high yielding; and, (iii) a smallholder age-yield profile.

18/ As noted earlier, use of an average age-yield profile neglects the effects of improvement in varieties over time (see footnote 16). Since the age-yield profile used is for a recent period, potential output as we have calculated it will tend to over-state true potential output in earlier periods (and understate it in future periods), since younger trees in earlier times yielded less than do trees of comparable age today. Our estate data will make possible some adjustment for this phenomenon in future analysis.

19/ Of course, to the extent that the alternative crops are also perennials, e.g., oil palm in Malaysia, their current prices relative to long-term expectations will matter.

20/ Since, under the assumptions, the method is maximum likelihood, we could derive the unconditional standard errors from the information matrix. Past experience shows this refinement typically makes little difference.

21/ We also ran this regression using the official area statistics; the result shown below is similar to the estimates derived using the revised data.

$$R_t = \underset{(11.20)}{-20363} - \underset{(1.11)}{14.22}\,(P_{t-1} - P^e_{t-1}) + \underset{(7.54)}{202.1}\,P^e_{t-1} + \underset{(6.89)}{0.819}\,s_{t-1}$$

$$+ \underset{(3.20)}{0.0315}\,AGE31\text{-}35 + \underset{(6.70)}{0.0541}\,AGE\ 36\text{-}40$$

$\bar{R}^2 = 0.930$ D.W. = 1.39

$\beta = 0.149$

22/ We also ran the same regression using the ratio of current rubber prices to wages. The ratio proved insignificant, and both the significance of the time trend and first-order residual serial correlation were enhanced.

23/ It has been suggested that the rate of such improvement has greatly slowed in recent years. If so, this will have significant effects on rubber supply response in both the short- and long-run since it will make waiting to replant at any point in time a less attractive alternative.

24/ This same assumption is the basis for the replanting model developed in the text. A problem arises from its applicability to smallholders, as discussed above.

25/ These plantings were allegedly made in former coffee-producing areas in the higher elevations, as a result of the decline in the turn-of-the-century coffee prices relative to rubber prices. Such plantings were made in ignorance of subsequent experimental results indicating the deleterious effect of higher elevations on rubber yields.

26/ The total acreage in 1921 according to Snodgrass is 390,170.9; however, according to the ARRC, the 1934 age distribution records 461,441 acres survived until 1934. Therefore, a straightforward use of Snodgrass's estimates was not possible.

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