# THE MARKET FOR GUAYULE RUBBER

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PREFACE

In 1980, IIASA joined together with the Centro de Investigacion en Quimica Aplicada (CIQA) to study resource development alternatives for arid and semi-arid regions. This joint effort is motivated by the perception that planning and programming of development projects, as they typically are applied to projects for drylands, are inadequate and pose serious obstacles to successful development of these regions.

Two characteristics distinguish the problem of planning and programming development projects for drylands. First, all of the common difficulties that beset development planning and programming (e.g., inadequate data, importance of poorly understood social and cultural relations, inadequate infrastructure, inadequate organization capacity) are present in the extreme. Second, even very modest-sized development projects are usually enormous in relation to the social, economic, and technical structure of drylands regions; their ramifications are little short of revolutionary.

To focus our efforts to improve planning and programming methodologies for dryland regions, it was decided to examine a specific problem: the prospects for developing a dryland region in northern Mexico based on the exploitation of 6 vegatal resource native to the region. A description of this study is available in

> Anderson, R.J., E. Campos-Lopez, and D. Gourmelon. An Analysis of Renewable Resource Development Alternatives for the Northern Arid Region of Mexico: Study Prospectus. WP 81-7. International Institute for Applied Systems Analysis (January, 1981).

Guayule (parthenium argentatum gray) is one of the vegetal resources under investigation in this study. Guayule shrub, which grows wild on the sierras of the Chihuahuan Desert, produces a high molecular weight hydrocarbon that can be processed into a premium-quality rubber. For approximately 50 years during the first half of this century a small but important guayule rubber industry operated in Mexico.

The Mexican government currently plans to reactive the guayule rubber industry using shrub harvested from wildstands as the basic source of shrub. This paper examines a critical aspect of this plan, the future market conditions under which a guayule rubber industry would operate. In subsequent papers, projected demand conditions will be compared to information concerning probable production costs to determine whether guayule rubber production is feasible economically.

ACKNOWLEDGEMENTS

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CONTENTS

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## 1 INTRODUCTION

This paper considers the potential market for guayule rubber. Its objective is to develop conditional forecasts of the parameters of this market that are needed to analyze the economic feasibility of the production of rubber from guayule.

Two previous analyses of guayule rubber commercialization have examined the potential market for guayule rubber. Foster et al (1980), in their technology assessment of the prospects for guayule development in the USA, forecast that the supply of natural rubber from hevea will fall far short of the potential demand for natural rubber. This shortfall, according to their analysis, provides a large potential market for guayule rubber. Nivert et al (1978) forecast future world prices for natural rubber using a forecasting model developed by Firestone. In their analysis, price forecasts, in relation to guayule rubber production costs, determine the economic feasibility of producing rubber from guayule.

Common to both approaches is the implicit assumption that natural rubber from guayule and natural rubber from hevea are perfect substitutes. Foster et al assume that guayule rubber could be used on a unit-for-unit basis to meet some or all of the projected shortfall between potential natural rubber demand and hevea rubber supply; Nivert et al assume that guayule rubber would sell for the same price as hevea rubber.

The analysis in this paper is also based on the premise that the rubbers derived from guayule and hevea may be treated legitimately as perfect substitutes. Evidence on the properties and performance characteristics of guayule rubber accumulated as a result of CIQA's R&D efforts supports this assumption.

Our examination of the potential market for guayule rubber adopts the basic approach followed by Nivert et al (1978). That is, it attempts to forecast ranges of future world market prices for natural rubber. Two objections may be levelled at this approach. First, according to one knowledgeable analyst of the rubber industry [Allen(1972, p. 173)], natural rubber price forecasting is fraught with pitfalls.

> There is no objective basis for estimating long term price movements of natural rubber. There are too many imponderables, and all that can be done is to have recourse to intuition aided by an intelligent reading of the world scene.

Second, the objection could be raised that the focus should be on prices and/or quantities in the Mexican market--thus concentrating on market potential in the Mexican market--instead of world market magnitudes. The justification for this position is that an objective of Mexico's economic development plans is to promote national independence in strategic materials.

While the importance of these objections is not to be denigrated, world market price is an absolutely essential ingredient in the determination of the economic feasibility of producing rubber from guayule. According to the usual criterion of economic feasibility [ see Squire and van der Tak (1975)], if rubber cannot be produced from guayule at a social cost less than its social value, then its production, by definition, is not economically feasible. In many (though not all) cases, the international competitive market price of a commodity like rubber and its social value could be assumed to be approximately equivalent. Even in cases in which social value and international market price differ, the international competitive market price usually is taken as the starting point for a series of adjustments reflecting social value. This is the reason the present analysis concentrates on future world prices instead of future world quantities or Mexican market prices and quantities.

With regard to Allen's pessimism concerning the likelihood of obtaining useful price forecasts, it can only be agreed that the matter is most difficult. It should be noted, however, that recent progress has been made in constructing natural rubber price forecasting models. Examples include the Charles River Associates-Wharton Model, and models developed at the World Bank, as described in Grilli et al (1980). It should also be noted that Allen's penetrating analysis of competition and pricing in rubber markets provides many useful clues on which forecasts could be based--clues that are depended heavily upon in subsequent sections of this paper. Finally, to guard against undue reliance on single forecasts, several alternative forecasts are prepared under different assumptions about market conditions.

The analysis presented below will show that, under plausible circumstances, there is a relationship between the prices of synthetic rubbers and the prices of natural rubber. In particular, it will be shown that synthetic rubber prices define a band within which natural prices tend to fluctuate. Moreover, it will be shown that synthetic rubber prices can be explained in terms of a few important exogenous factors, including feedstock costs, technological change, and economies of scale. Thus, using the relationship between synthetic rubber prices and natural rubber prices, natural rubber prices may also be related to these three factors.

The plan of the paper is as follows. Section 2 develops a theory of price determination in rubber markets. In developing this theory, we proceed from the simplest possible economic model to more detailed models that consider market segments and the nature of competition in rubber markets. The objective in this section is to develop a conceptual basis for empirical analysis of past price patterns and for econometric forecasts of future prices.

Section 3 formulates and estimates an econometric model that explains synthetic and natural rubber prices. It should be emphasized that the model developed in Section 3 does not begin to approach those described in Grilli et al (1980) in structural detail and complexity. Indeed, the model presented and estimated here is just about the simplest imaginable model. As the analysis and discussion in Section 3 will show, however, this model provides a reasonably satisfactory empirical description of past price behavior. Given the broad scope of the investigation of guayule of which this market investigation is one part, the model provides a workable if simple tool for forecasting future rubber market price patterns.

Section 4 presents some very tentative conditional forecasts of future natural rubber prices. These conditional forecasts are based on extrapolations from the model presented in Section 3 under alternative assumptions about world economic conditions, oil prices, and trends in technology. The conditional forecasts presented in Section 4 show that, under plausible conditions, the real (i.e., adjusted for increases in the general level of prices) price of natural rubber may be expected to be constant or to rise.

## 2 PRICE DETERMINATION IN RUBBER MARKETS

### a Basic Principles

It will facilitate discussion of the determination of world prices for rubber if the basic economics of price and output determination in domestic markets are reviewed. To begin, assume that the national market in question (say the Mexican market for rubber) is completely open (i.e. that there are no barriers to trade) and that the market is perfectly competitive. The possible consequences of removing some of these assumptions are explored later in the paper.

Determination of output and price in a competitive open domestic market is depicted in Figure 1. Curve D-D in this figure represents the domestic demand for rubber. Curve $P_w$ represents the world price for rubber, and curve $S_o$ represents the domestic supply of the rubber. Ignore the curve $P_d$ for the moment.

Under the competitive open market assumption, domestic producers may produce and sell as much output as they wish at the world price, $P_w$. In this situation, domestic producers would produce a quantity corresponding to the point at which the domestic supply curve, $S_o$, intersects the world price curve, $P_w$. Output also would be sold domestically at the world price. Hence, domestic producers would produce $Q_1$ units of rubber per unit of time, and domestic consumers would purchase $Q_2$ units of rubber per unit of time. The difference, $Q_1 - Q_2$ would be

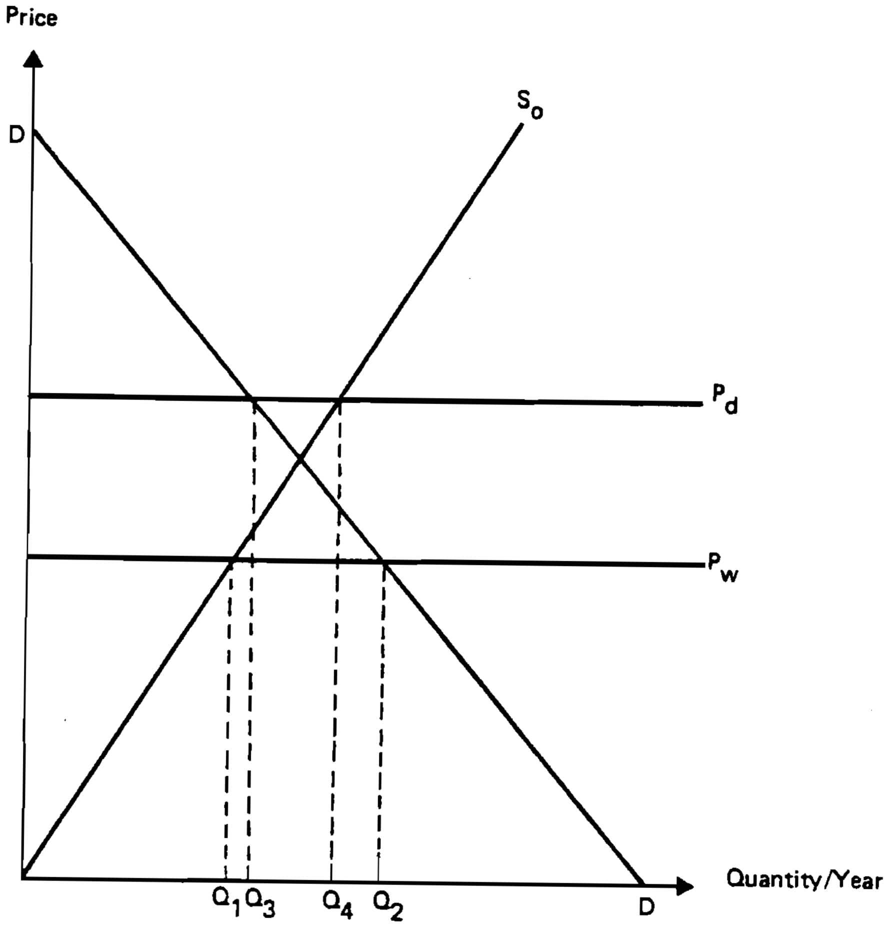


Figure 1. Price and output determination.

imported.

It should be pointed out that the case depicted in Figure 1 is the special case in which the world market price for the commodity is below the price at which domestic. supply and demand intersect. In this case, Mexico would be a net importer of rubber. It could as well happen that the world price would be above the price level at which domestic supply and demand are equal. In this case Mexico would be a net exporter of rubber.

Now let us drop the assumption that the Mexican rubber market is completely open to trade, and consider the case in which this market is insulated from the world market via a tariff on imports. In this case, the domestic price, $P_d$, and the world price would differ by the amount of the tariff. In the case shown in Figure 1, it is assumed that the tariff is large enough to boost the domestic price above the price at which domestic supply and demand intersect. (Again this need not necessarily be the case. A lower tariff level could result in a domestic price lower than the price at which domestic supply and demand are equal.) In the case shown in Figure 1, the tariff results in an excess of domestic supply over domestic demand. The excess, given by $Q_4-Q_3$ in the figure, would have to be either stockpiled or exported (with subsidy) at the world price.

The analysis in Figure 1 clarifies just what market data are needed to conduct our economic analysis of guayule projects. In particular, if the market for guayule rubber is competitive and open, then forecasts of the world price of guayule rubber will suffice. This price is approximately the price that Mexican producers could expect to face. If, in contrast, the Mexican rubber market were insulated from the world market via a tariff or some other impediment to imports, then domestic price and quantity demanded must be known. One presumably also would want to have some idea of the domestic supply that would be forthcoming at this price since provision would have to be made for stockpiling or for subsidized export. However, as was remarked in Section 1, since our ultimate objective is to analyze the economic feasibility of guayule rubber production, and since this analysis requires world market price as a basis for further calculations, the market analysis will concentrate on the world market price for rubber.

There are two complications to be dealt with to extend the simple analysis depicted in Figure 1 sufficiently so that it is an adequate characterization of rubber markets. First, the rubber market is in fact more than one market. There are a staggering array of types of rubber available. The degree of substitutability among them varies widely. Our analysis must be extended to account for this characteristic.

Second, the above analysis assumes a competitive market. This assumption clearly warrants examination. Concentration in rubber markets is nonnegligible, as will be discussed below, and there have been intermittent moves by national and international authorities to intervene in the market for natural rubber to influence prices.

In the following paragraphs, the above analysis is extended to account for these characteristics. The extensions developed below will also provide a theoretical basis for empirical analysis of world rubber market prices.

### b Market Segments

As noted above, there are a large number of types of rubber products available on world markets. Clearly some distinction must be made among these in any reasonable model of rubber markets. Just as clearly, it is impractical to develop a model for every distinct type of rubber. Fortunately, it appears to be possible to analyze market prices and quantities adequately in terms of a limited number of submarkets.

#### 1 Bases for Segmentation

A distinction is sometimes made between segments of the rubber market. Some analysts divide the market into a specialty segment, where the substitutability between natural and synthetic rubbers is relatively low, and a general purpose segment, in which substitutability is relatively high. Predicasts (1978, p 52) describes this segmentation as follows:

> ...It is widely accepted that in a large number of product applications where the main determinants in selection are price and availability, natural and synthetic rubbers are close substitutes. Additionally, natural rubber, SBR, BR, and IR compete where a general purpose rubber with standard properties is needed. In the case of specialty rubbers, many have been

> developed for use in a specific product or isolated market, and thus there is minimal substitutability, especially with their relatively high prices.

This certainly is not the only possible or reasonable way in which the market can be segmented. Allen (1972, pp 17-18) prefers a division of the market into three segments based mainly on market volume.

> As far as the rubbers are concerned a fact of dominant importance is that 60-70 percent of the world's rubber is used to make tyres. This, combined with the influence of price and performance, has the effect of splitting the family of rubbers in three sharply differentiated groups which may be termed (i) large-tonnage rubbers, (ii) medium-tonnage , and (iii) small-tonnage rubbers. The defintion of these is as follows. The large-tonnage group consists of those rubbers of minimal cost whose performance is such that they can be used to make tyres and the bulk of 'general rubber goods'. These rubbers sell at prices roughly in the range £150-300 per ton. The medium-tonnage group contains those rubbers which either sell at significantly higher prices (because of the nature of their production processes) and/or have one or more performance defects rendering them unsuitable for tyres; they are used for the manufacture of a wide variety of general rubber goods. The small tonnage group contains those rubbers which are not only of high price (sometimes very high) but are also unsuitable for mainstream rubber products.

Allen (1972, p 18) places five rubbers in the large-tonnage group: natural rubber, styrene/butadiene rubber, polybutadiene, synthetic polyisoprene, and ethylene/propylene rubbers. The first three members of this group had already [at the time Allen wrote] attained large market volumes. The latter two members of the group [synthetic polyisoprene and ethylene/propylene rubbers] were placed in the large tonnage group on the basis of Allen's appraisal of their future potential.

Grilli et al (1980, p 43) agree that this three segment characterization of the market is particularly useful for studying price behavior in rubber markets since most of the competitive interaction takes place in the large tonnage segment.

> Even though no unique classification will be adopted in this study, the one proposed by Allen is quite useful for the purpose of examining the competition between NR [i.e. natural rubber] and SR [i.e. synthetic rubber], since the prices of the four large tonnage SRs historically have been in the range of natural rubber prices, and their markets have overlapped those of NR to a greater or lesser extent.

Allen (1972, p 122) further subdivides the large-tonnage market, on the basis of competition, into three subsegments.

> ...The effect of technical differences between the rubbers (which are not as great as is sometimes suggested), overlaid with supply and price factors, is to split the usage pattern three ways: (i) products where natural rubber is preferred at virtually any price, (ii) those where a particular synthetic is preferred, and (iii) products where the choice is open. The split is far from sharp and varies from country to country. As a further complication, many products are today made from blends of natural rubber with a synthetic.

In sum, experienced analysts have found it both useful and valid to analyze the rubber market in terms of a few segments. There is, to be sure, some disagreement about which segmentation is most useful. Discussion of this issue and choice of a segmentation for our analysis is deferred until the effect of segmentation on market price and output determination has been examined. We turn now to this subject.

## 2 Effect of Segmentation

Under the segmentation hypothesis, the determination of prices and outputs of synthetic and natural rubbers is a little different than that explained in Section 2a above. In that analysis, recall, a single market was examined. It was thus implicitly assumed that synthetic and natural rubbers are perfect substitutes in all uses. As the above discussion indicates, this assumption must be relaxed.

To see the effect of segmentation, let us first adopt a very simple assumption about the nature of the segmentation of the market. This assumption will be relaxed below. Let us begin by assuming that the market may be divided into two segments [e.g. a "general purpose segment" and a "specialty segment"], and that in the general purpose segment, synthetic rubber and natural rubber are perfect substitutes. In the specialty segment, however, it is assumed that only natural rubber may be used. It is assumed that there are only two kinds of rubber--"natural" and "synthetic". In addition, it is assumed that the supply of synthetic rubber is perfectly elastic and that the supply of natural rubber is perfectly inelastic. Competitive behavior in both segments also continues to be assumed.

The price and quantity outcomes in this situation are critically dependent upon demand conditions in the general purpose and specialty markets. If specialty demand is sufficiently great that the entire output of natural rubber can be absorbed in this market at a price higher than the price for rubber in the general purpose segment, then all natural rubber will be consumed in the specialty segment. If, however, demand in the specialty segment is not sufficiently great to absorb the entire supply of natural rubber at a price above the price in the general purpose market, then the fixed supply of natural rubber will be divided between the general purpose and specialty markets and will sell at the same price [equal to the price of synthetic rubber] in both.

Price and output determination in these market segments may be illustrated easily. In panels (a) and (b) of Figure 2 below, supply and demand curves are drawn depicting conditions in the two market segments of the model. Panel (a) depicts the situation in the general purpose segment. In this panel, curve $D_g$ represents market demand for general purpose rubbers, and the curve $P_s$ represents the market supply curve for synthetic rubber. This curve is drawn horizontally reflecting the assumption that the supply of synthetic rubber is perfectly elastic.

Panel (b) represents the situation in the specialty segment of the market. Curve $D_s$ represents demand for specialty rubbers, and curve $N_1$ represents the supply of natural rubber. [Ignore $N_2$ and $N^*$ for the moment]. For easy reference, the supply price of synthetic rubber is projected across to panel (b).

Under the conditions described above, the entire supply of natural rubber can be absorbed in the specialty market at a price above the supply price of synthetic rubber. In this case,

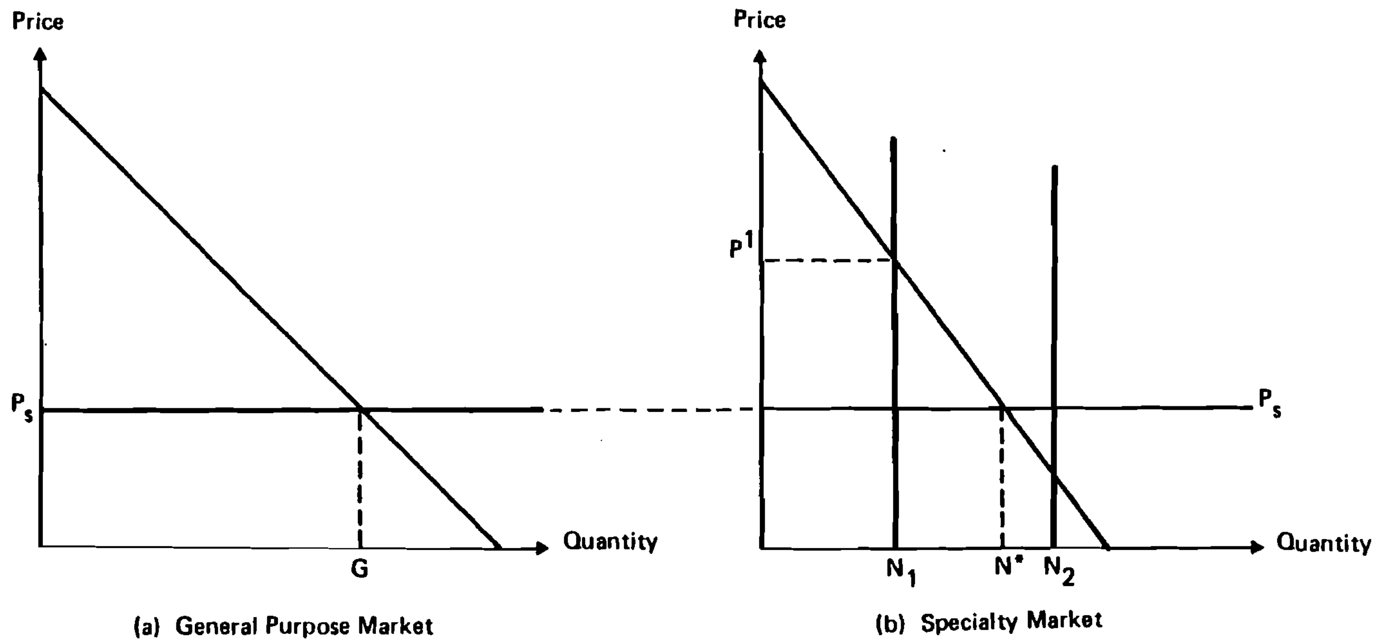


Figure 2. A market segmentation model.

the entire supply of natural rubber would be sold in the specialty market at a price of $p^1$ (see panel (b)). The entire demand for general purpose rubber would be met by synthetics at the supply price, $P_s$. The market quantity of general purpose rubber would be G (see panel (a)). Note that in the case discussed above, the market price for natural rubber would be above the market price for synthetic rubber.

Now let us suppose that the supply of natural rubber were $N_2$ instead of $N_1$. In this case, if the entire quantity of natural rubber were sold on the specialty market, the price of natural rubber would fall below the price it could be sold for on the general purpose market. In this case, not all of the natural rubber would be sold on the specialty market. It would be split between the general purpose and specialty markets in whatever proportions were required to equalize the price of natural rubber on the two markets. But natural rubber could never sell for more than the price of synthetic rubber in the general purpose segment because, under our assumptions, the two types of rubber are perfect substitutes in this segment. In the case depicted in panel (b), $N^*$ units of natural rubber would be used in the specialty market and $N_2-N^*$ would be used in the general purpose market. The price of natural rubber in both markets would be $P_s$. If $N_2-N^*$ were larger than G (that is, if the excess supply in the specialty market at the general purpose market price were bigger than the demand in the general purpose market at that price), then prices in both markets would fall below the price of synthetics, and natural rubbers would fill the entire demand of both markets.

The most important implication of this model of the rubber market is that the price of natural rubber would fluctuate, usually above the price of synthetic rubber, and its share of the general purpose market would also fluctuate. If demand in both markets were very weak, it could happen in the context of this model that natural rubber would take over the entire market, and that the price of natural rubber would fall below the price of synthetic rubber.

It is useful to further extend the above model by relaxing most of its simplifying assumptions. In particular, we introduce a third market segment, a specialty segment in which only synthetic rubber is used, and the assumptions that the supply of synthetic is perfectly elastic and that the supply of natural rubber is perfectly inelastic are relaxed. Unfortunately, when these assumptions are relaxed, it becomes difficult to depict the analysis graphically, and the methods of mathematical analysis must be employed.

For this purpose, let us adopt the following notation and definitions:

$S(s_1+s_2) = S(s_t)$ = supply of synthetic rubber

$s_1$=quantity of synthetic consumed in the synthetics only market segment

$s_2$=quantity of synthetic consumed in the general purpose market segment

$N(n_2+n_3) = N(n_t)$ = supply of natural rubber

$n_2$=quantity of natural rubber consumed in the general purpose market segment

$n_3$=quantity of natural rubber consumed in the natural only market segment

$s_t, n_t$=respectively the total quantities of synthetic and natural rubbers produced/consumed

$D_1(s_1)$=inverse demand function in synthetic only market

$D_2(s_2+n_2)$=inverse demand function in general purpose market

$D_3(n_3)$=inverse demand function in natural rubber only market

To deduce the nature of the equilibria in these markets, we assume that the operation of the markets is such as to maximize the sum of producers' plus consumers' surplus in the markets, subject to the constraints that all of the quantities must be nonnegative. That is, we seek the solution to

$$\text{Maximize: } \int_0^{s_1} D_1(v_1) + \int_0^{s_2+n_2} D_2(v_2) + \int_0^{n_3} D_3(v_3)$$

$$- \quad S(s_1+s_2) \quad - \quad N(n_2+n_3)$$

subject to:

$$s_1, s_2, n_2, n_3 \;\geq\; 0$$

The necessary conditions for solution to this problem provide much information about the resulting market equilibria. The first order conditions are

(1a) $D_1(s_1)-S(s_t) \leq 0$ and $[D_1(s_1)-S(s_t)]s_1=0$

(1b) $D_2(s_2+n_2)-S(s_t) \leq 0$
and $[D_2(s_2+n_2)-S(s_t)]s_2=0$

(1c) $D_2(s_2+n_2)-N(n_t) \leq 0$
and $[D_2(s_2+n_2)-N(n_2)]n_2=0$

(1d) $D_3(n_3)-N(n_t) \leq 0$ and $[D_3(n_3)-N(n_t)]n_3=0$

It is relatively easy to interpret these conditions and to see what they imply for the nature of equilibria in the three segments of the rubber market. Let us first examine condition (1a), which is exactly like each of the other conditions. The first part of the condition says that the demand function in the synthetic only market evaluated at the quantity $s_1$ must yield a value of price no bigger than the supply function for synthetic rubber yields when evaluated at the total quantity of synthetics supplied. To see why this is a necessary condition for equilibrium, suppose that $D_1(s_1)$ were greater than $S(s_t)$. This would mean that the price that buyers of synthetics in the synthetic only market would be willing to pay would be higher than the price that suppliers would ask in order to produce the total quantity needed to meet both the demands in the synthetics only and general purpose markets. Suppliers would respond by producing more synthetics and/or shifting synthetics from the general purpose to the synthetic only market. This supply response would continue until there were no incentives to expand sales in the synthetic only market; that is, until the demand price in the synthetic only market is no greater than the supply price for synthetic rubber.

The second part of condition (1a) indicates under what circumstances the demand and supply prices in the synthetic only market must be exactly equal. In particular, since the product of the equilibrium quantity times the difference between the demand and supply prices must be equal to zero, we know that whenever the quantity of synthetic consumed in this market is positive (i.e. whenever $s_1$ is strictly greater than zero), demand and supply prices must be equal (i.e. $D_1(s_1)-S(s_t)$ must be exactly equal to zero). Equation (1a) also implies that whenever the quantity of synthetic consumed in the synthetic only market is zero, then the difference between demand and supply prices may be nonzero, subject to the proviso explicit in the first part of the condition that it be nonpositive.

Each of the other conditions shown in Equations (1b)-(1d) may be interpreted in precisely the same manner. However, these equations, taken together, have still more to say about the relationships between equilibria in the various markets.

Note first from equations (1a) and (1b) that in equilibrium, the supply price of synthetic rubber in both the synthetic only and general purpose markets must be equal. This can be seen by noting the $S(s_t)$ appears in both equations. It follows from our discussion above that if positive quantities of synthetic rubber are consumed in both markets, then the price of synthetic rubber must be the same in both markets. Otherwise the condition that the product of the difference between supply and demand price times quantity be zero could not be met simultaneously, as required by equations (1a) and (1b).

This result can also be given a very simple heuristic interpretation. Suppose that the price of synthetic rubber in the two markets were different. Then buyers would switch their purchases to the market in which the price was lower, thus putting upward pressure on price in the low price market and downward pressure on price in the high price market. This process would cease only when the incentive created by price differentials between the two markets had been eliminated. But that is exactly what the equilibrium condition discussed in the preceding paragraph requires.

Note from equations (1c) and (1d) that the supply prices of natural rubber in both the natural only and general purpose markets also must be equal. It also follows, for the same reasons as discussed above, that if positive quantities of natural rubbers are consumed in both markets, then the prices of natural rubber must be the same in both markets.

Finally note by inspection of equations (1b) and (1c) that if strictly positive quantities of both natural and synthetic rubber are sold on the general purpose market, then their prices must be the same. This follows immediately from our assumption that the two are perfect substitutes on the general purpose market. If one were to sell for a higher price than another, then shifts in demand to the lower priced rubber of the two would put pressure on prices that would only be eliminated when they were equal.

Under completely general assumptions about supply and demand in the various market segments it is no longer possible to conclude that the price of natural rubber usually would fluctuate above the price of synthetic rubber. In the general case, for example, it could happen that demand in the synthetic only specialty segment were sufficiently great so that no synthetic would be sold in the general purpose segment. In this case (and in others not discussed here) it could well happen that the price of synthetic rubber would be above -- perhaps well above -- the price of natural rubber.

Fortunately, it does not appear to be necessary to keep our assumptions at the level of complete generality. The supply of synthetic rubber appears to be highly elastic, and the supply of natural rubber appears to be highly inelastic [see Section 3 for a summary of the evidence on this point]. In this case, the general conclusions reached in the context of the simpler two segment model remains valid: the price of natural rubber generally would fluctuate above the price of synthetic rubber; and the share of natural rubber in the markets in which it competes with synthetic rubber would vary inversely with demand. More will be said about relative elasticities in Section 3 below.

It should be noted that the assumptions that natural and synthetics are perfect substitutes in the general purpose segment and cannot be substituted at all in the other segments can be relaxed without affecting the basic structure of the conclusions of the analysis. Different degrees of substitutability could be admitted. In this case, it would no longer be true that the prices of both types of rubber would have to be equal if both were sold in the general purpose segment. It would still be true however that the same type of rubber could not be sold at different prices in different markets. And the qualitative conclusions concerning the pattern of price fluctuations and market share fluctuations discussed above could still be expected to hold.

Depending upon the pattern of substitution elasticities assumed in the various segments, one could also deduce additional implications about probable price relationships. For example, some degree of substitutability in the natural rubber only segment would tend to provide a ceiling on natural rubber price fluctuations in addition to the floor deduced above.

## 3 Implications vs Data

Interestingly, broad comparisons of prices of natural and synthetic rubber are basically consistent with the prediction that natural rubber prices will tend to fluctuate above synthetic rubber prices. In Figure 3 below, a summary is presented of

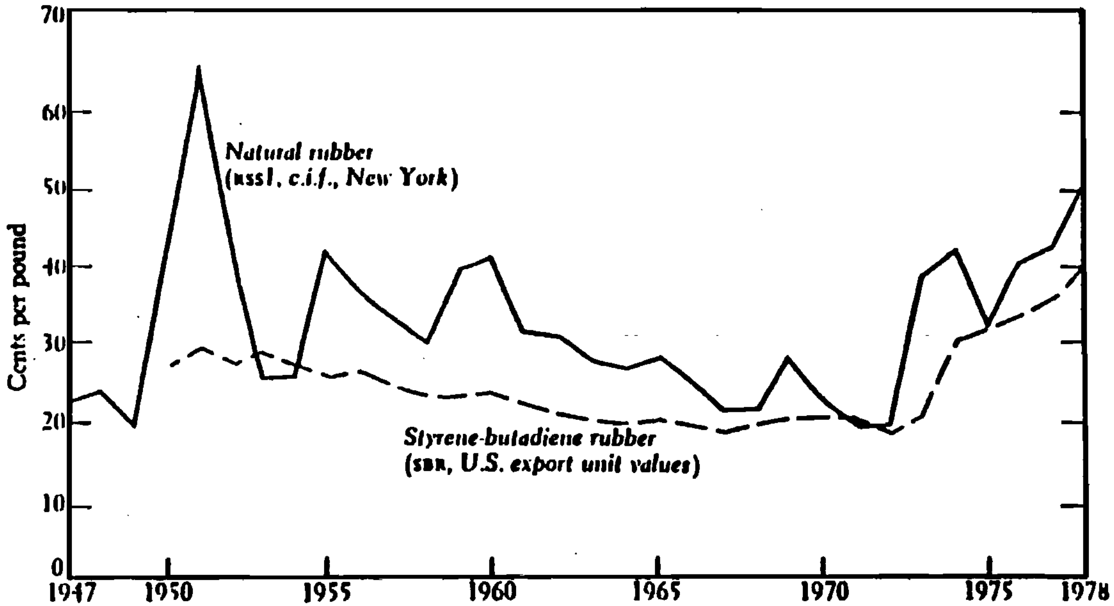


Figure 3. Rubber price patterns.

the behavior of prices for RSS 1 and SBR (the dominant synthetic rubber) over time. As can be seen, with the exception of the period during the Korean War and the post-Korean War stockpile liquidation, the price of RSS 1 has remained above that for SBR.

Allen (1972, pp 165-166) has provided additional evidence concerning the relationship between natural and synthetic rubber prices. He notes that fluctuations in natural rubber prices have tended to become progressively less pronounced over the postwar period, and attributes this to the threat of competition from synthetics. He also notes that the real price of natural rubber (i.e. nominal price deflated by a price index) has tended to fall over the postwar period, and also attributes this to "the dampening effect of synthetics". He concludes

> To sum up, the emergence of the synthetics has indirectly influenced the prices paid for natural rubber by suppressing these below the hypothetical levels which would have been seen in the absence of synthetic rubbers. The most directly observable influence of the synthetics has been to regulate the price fluctuation and to impose progressively lower ceilings on the peaks.

Grilli et al (1980, p 38) also conclude that synthetic rubber prices have had an important effect on natural rubber prices.

> From the early 1950s, when production of SR began on a large scale, to the early 1970s, the trend in natural rubber prices continued to decline. The main cause was the steady fall of synthetic rubber prices brought about by economies of scale and by technical progress in the world rubber industry. As SR became progres-

> sively more and more important in world markets, its prices set the overall trend, and natural rubber producers became to a large extent, price takers.

Another implication of the theory developed above that is confirmed by the data is that the share of the market captured by natural rubber tends to rise when the demand for rubber (natural and synthetics) falls. Grilli et al (1980, p 63) note

> When world demand for all elastomers dropped quite drastically in 1975 as a consequence of the economic recession in industrialized economies, natural rubber prices declined to an anverage of 30 cents [US] a pound, c.i.f. At this price level, neither IR [i.e. polyisoprene synthetic rubber] nor SBR could compete with NR. In a declining total market, the share of NR increased, whereas that of IR and SBR declined correspondingly.

Econometric investigations [see Grilli et al (1980, pp 112-116)] provide additional evidence that the market share of natural rubber varies inversely with total demand for rubber. Using a market share model relating market share to the price of natural rubber [as measured by the price of RSS 1] relative to the price of synthetic rubber [as measured by the price of SBR 1500], Grilli et al find a statistically significant negative relationship between relative price and market share. Since natural rubber prices tend to vary with total rubber demand while synthetic rubber prices tend to be relatively constant [on this point, see the discussion in Section 2.c.2 below], these results are consistant with the hypothesis that the market share of rubber varies inversely with total demand.

The three segment model discussed above is basically consistent with the characterization of market structure adopted by Allen. Each segment might best be thought of as a portion of what Allen calls the large-tonnage market. The implications of this model seem to be consistent with observed price and output behavior in rubber markets. Accordingly, subject to the discussion in the next section of assumptions concerning market structure, we provisionally conclude that the three segment model described above provides a useful basis for empirical work.

### c Competition in Rubber Markets

It was remarked above that the basic models of price and output determination explored in Sections 2a and 2b assume that the various market segments are competitive [in the economist's sense of that term]. Yet it is well known that there have been several attempts to interfere with the workings of the market. In 1922, for example, the British Government became alarmed at the steady decline in natural rubber prices that began in 1911. In an effort to reverse the trend, a plan [known as the Stevenson Scheme in honor of its propounder] to restrict output in British-controlled producing countries was adopted. Most observers credit the plan with a marked increase in natural rubber prices over a period of a few years. However, these high prices also stimulated competition, according to Allen (1972, p. 44), which eventually led to the collapse of the scheme and to a slump in the market.

More recently, consuming and producing nations negotiated an international agreement on rubber under the auspices of UNCTAD. This agreement, The International Natural Rubber Agreement, was reached in late 1978. Under its terms, producers and consumers have agreed to share equally the responsibilities and benefits of price stabilization, which is to be achieved through an internationally managed and financed buffer stock.

The assumption that rubber markets are competitive thus clearly warrants critical examination. We turn now to this subject.

### 1 Demand

The demand for rubber is dominated by the demand for rubber for tire manufacture. Consumption of rubber in tire manufacture accounts for 60 to 70 percent of all rubber consumed worldwide.

Tire manufacture is heavily concentrated. Over the mid-1970's, four multinational tire companies (Goodyear, Dunlop-Pirelli, Firestone, and Michelin) accounted for 60 percent of worldwide tire production. The largest eight firms (which, in addition to the above-mentioned companies, include Uniroyal, Goodrich, General Tire, and Bridgestone) accounted for 85 percent of total tire production. Demand for rubber for tire manufacture which is a very important portion of total demand, is thus highly concentrated.

There are no readily available data on concentration of demand for non-tire uses of rubber. What evidence there is, however, suggests that this demand is not concentrated.

No data are available on the concentration of demand by segments of the large-tonnage rubber market. However, since tire manufacture clearly falls in the market segment in which synthetic and natural rubbers compete, it is probable that demand is very highly concentrated in this segment. Demand probably is much less concentrated in the synthetics only and natural only segments.

2 Supply

The structures of supply of natural and synthetic rubbers are quite different. While natural rubber is produced on large plantations, a substantial portion of the total supply is accounted for by smallholders. In terms of sheer numbers of independent producing entities, supply of natural rubber appears to approximate the hypotheses of the competitive model.

Allen (1972, p 162) has inferred that natural rubber markets have many of the characteristics of perfectly competitive markets.

> Like most commodities, natural rubber is sold via international open markets from the multiplicity of producers to the consumers. These markets display most of the features of 'perfect competition': there are large numbers of buyers and sellers, so that no one faction dominates, and there is full published knowledge of the prices being paid each day. It is of the very nature of such marketing arrangements that the price cannot be fixed but must fluctuate according to the operation of supply and demand...

Although one cannot dispute the historical variability of natural rubber prices, and one certainly cannot dispute that there are a large number of producers of natural rubber from hevea, Allen's conclusion must be tempered on three grounds. First, as noted above, demand concentration may not be negligible, and therefore the potential exists for departure from competitive behavior on this side of the market. Second, natural rubber production is heavily concentrated in a few producing countries. These countries can and do [as is exemplified by production quotas and export restrictions adopted during the 1975 rubber market slump] take actions that affect the workings of the market. Third, the International Natural Rubber Agreement [see above] may affect the nature of future competition in world rubber markets.

It is hard to assess the significance of these non-competitive aspects of the supply of natural rubber. The persistent loss of market to synthetics serves as a constant reminder to any who might contemplate the exercise of market power via control of the supply of natural rubber that competition from synthetics must be reckoned with. Undoubtedly this recognition has been a powerful deterrent in the past. Whether or not it will continue to provide a powerful deterrent in the presence of rapid increases in the cost and possible interruptions in deliveries of critical inputs for synthetic rubber production is a difficult and important question.

As was remarked above, the structure of supply of synthetic rubbers is very different from that for natural rubber. Production tends to be dominated by relatively large firms. It has been estimated that there are approximately 100 producers of synthetic rubbers worldwide. Many synthetic rubber producers are integrated vertically, backward into petrochemical production and/or forward into tire production, and/or horizontally across the range of rubber products. Grilli et al (1980, p 16) conclude of the structure of synthetic rubber supply

> The present world market for SR [synthetic rubber] is clearly oligopolistic in structure and is characterized by only limited price competition among the large producers.

An examination of marketing and pricing practices bears out this conclusion. Synthetic rubbers are sold, in general, directly from producers to manufacturers at prices related to published list prices. Synthetic rubber prices, until recently, have tended to be relatively stable, as can be seen by examining Figure 3. Allen (1972, pp 167-169) has cautioned, however, that natural rubber prices are not quite as variable and synthetic rubber prices are not quite as stable as available price information implies.

> The comparison is not as stark as this, nor is it quite so simple. Some natural rubber is sold direct...; this is especially the case for large manufacturers buying rubber from chosen estates and, more recently, from smallholders' central processing factories. Such sales are almost certainly at prices which are more stable than the open market can provide. Then, the actual prices paid by a particular manufacturer for a given synthetic are not necessarily quite the same as the list price. Discounts may be available, and these will depend on the status of the buyer and may vary from time to time...

Nonetheless, Allen (1972, p 169) concludes that, on balance, the market prices for natural rubber and list prices for synthetics are reliable guides to overall market patterns.

> ...But these are marginal factors and it is an inescapable fact that the prices paid for synthetics are far more stable, over very long periods, than those paid for natural rubber, and this applies both for small and large lots.

### 3 Implications for Market Analysis

It is unclear whether or not, and if so in what respects, the analysis presented in Section 2b should be modified to reflect the features of rubber markets described above. Certainly it is fair to conclude that the <u>structure</u> of the market departs in several respects from the perfectly competitive market of economic theory. It is less clear, however, that observed price and output <u>behavior</u> in rubber markets departs significantly from predictions that one would make based upon competitive models discussed above. The evidence reviewed above [see Section 2b3] suggests that it does not. Accordingly, we shall proceed under the tentative conclusion that the competitive model provides a valid framework for analyzing the market.

## 3. EMPIRICAL ANALYSIS

In this section, a quantitative analysis of price and output determination in rubber markets is presented. This analysis is based on the qualitative models developed above.

## a. Supply and Demand Elasticities

Recall from the discussion in Section 2b that the qualitative predictions concerning the relationship between synthetic rubber and natural rubber prices depend critically upon relative supply and demand elasticities for both types of rubber. While there is relatively little econometric evidence on these elasticities, some plausible estimates [see Grilli et al (1980)] and qualitative conclusions about relative magnitudes [see Allen(1972, pp169-170)] are available.

In the short term, the supply of natural rubber is relatively unresponsive to price. This is because a period of approximately five years is required between the time _hevea brasiliensis_ is planted and the time it is first tapped. Another five years are required before it attains full-yield maturity. While it is possible to vary supply in response to price changes by varying harvesting effort, Allen notes that such supply responses have been detected only among smallholders, and that these responses have had only a marginal effect on the total supply of natural rubber. Quantitative estimates of supply elasticity, according to Grilli et al (1980, p 35) are on the order of 0.1 to 0.2.

In the longer run, the area planted in hevea could, in principle, be varied in response to changes in expected prices for natural rubber. Thus, one would normally expect long run supply elasticity to be somewhat higher than short run supply elasticity. According to Allen (1972, p 169), however, long run supply elasticity is also low.

> ...The assertion that natural rubber [supply] is price-elastic in the long term is questionable; it is certainly not dramatically so.

Less is known about the elasticity of supply of synthetics. Indeed, given the departures from competitive structure noted above and the "administered" nature of pricing in the industry, it is not clear whether it is even appropriate to speak of "supply".

What evidence there is suggests that price is not terribly sensitive to output rates. In the short term, prices for synthetic rubbers have tended to be very stable even during sharp output swings. Grilli et al (1980, p 38) attribute this to the oligopolistic structure of the industry. In the longer term, the price of synthetic rubber has tended to decline. The price evidence reviewed in Figure 3 shows that SBR prices generally fell over a period of time during which the output of synthetic rubbers grew approximately ten-fold. Declining SR prices over much of the period shown in Figure 3 reflect declining real cost of petrochemical feedstock over much of the period covered by our data, efficiency-improving technical change, and realization of economies of scale in petrochemical feedstock and synthetic rubber production. On this latter point, Allen (1972, p 170) notes

> Like all synthetic polymers and other petrochemical products, the synthetic rubbers have been able, so far,to use economies of scale so as to keep down production costs. Such economies are now starting to be-

come played out...

The jumps in price shown in Figure 3 since 1973 are not related to output changes, but rather to cost changes. These changes coincided with major changes in the cost of feedstock. Grilli et al (1980, p 5) observe of the effect of oil and gas prices on synthetic rubber production costs

> The production cost of SR depends heavily (as much as 70 percent of the total) on the costs of chemical feedstocks and energy inputs (such as steam and electricity), which are closely related to the costs of oil and gas. Between 1973 and 1975 the cost of the basic chemical monomers used in synthetic rubber production--styrene, butadiene, and isoprene--and of other chemical and energy inputs more than doubled.

It may be concluded that if it were appropriate to speak of the supply of synthetics [and it may be], the supply of synthetics appears to be highly price elastic.

On the demand side, Allen notes that short run demand elasticities are smaller than long run demand elasticities since rubber consumers cannot shift rapidly from natural to synthetic, or vice versa, in response to relative price swings. In the longer term, however, such responses can be made, and hence long term elasticities are higher. Allen attributes considerable importance to these relationships in limiting the swings in the price of natural rubber relative to synthetic rubber [see the discussion in Section 2b above]. According to Grilli et al (1980, p 35), short-run demand elasticities for natural rubber are on the order of -0.2 to -0.3.

Overall, Allen argues that the total demand for rubber is price inelastic in both the short and long terms.

> For the rubbers as a whole, demand is presumably rather inelastic both in the short and long term, bearing in mind that raw rubber accounts for quite a small proportion of the sales value of most rubber products...
>
> Allen(1972),p 171

b A Rubber Price Model

Evidence is presented above that trends in the prices of synthetic rubbers can be explained by technical change, economies of scale and learning, and input price changes. While it has been noted that synthetic rubber production is highly concentrated, there is no evidence that this concentration has had an effect on long term price trends. Such effects as concentration may have are likely to be on short term price behavior.

Evidence has also been presented that synthetic and natural rubber prices are linked. The theoretical analysis in Section 2 implies that synthetic rubber prices provide a floor [although not an absolutely rigid one] under natural rubber prices, and also constrain their upward movement. Indeed, given the ready expansibility of synthetic rubber output, Grilli et al (1980, p 38) have characterized natural rubber producers as "price takers" [see pages 25 and 26 above].

It follows that, if we could explain synthetic rubber prices, we would have much of the information needed to make an intelligent explanation of natural rubber prices. To make an explanation that also accounts for fluctuations in natural rubber prices, we would need in addition to consider total market demand.

This is indeed the direction taken below in developing a quantitative model. A model embodying these concepts can be formulated using two equations. The first equation, Equation (2), explains the price of synthetic rubber as a function of time, and the price of crude oil. Time is included as a proxy for technical change and/or the exploitation of economies of learning and scale. The price of crude oil is included as a proxy for the price of petrochemical feedstock. In particular, we specify

$$(2) \quad psrub_t = a_0 + a_1 \, time + a_2 \, poil_t + u_t$$

where "psrub" is the real price of synthetic rubber, "time" is a time trend variable, and "poil" is the real price of oil. The a's are unknown parameters to be estimated econometrically, and $u_t$ is a random variable. Based on the discussion above, we would expect the estimated value of $a_1$ to be negative, reflecting the effects of scale economies and technological developments described by Allen, and the estimated value of $a_2$ to be positive, reflecting the effect of crude oil prices on feedstock costs.

To complete this model, Equation (3) specifies the price of natural rubber as a function of the price of synthetic rubber and the rate of growth of OECD countries Gross Domestic Product. The former variable is included to capture the effect of synthetic rubber prices on natural rubber prices; the latter is included to capture the effects of demand shifts related to business cycle conditions. In particular

$$(3)\quad pnrub_t = b_0 + b_1\, ggdp_t + b_2\, psrub_t + e_t$$

where "pnrub" is the price of natural rubber, "ggdp" is the growth rate of GDP in OECD countries, $e_t$ is a random error, and the b's are unknown parameters to be estimated econometrically. Based on the discussion above, we would expect the estimated values of $b_1$ and $b_2$ to be positive.

The model embodied in Equations (2) and (3) is clearly a very simple model. It does not, for example, admit of any relationship between demand conditions and the price of synthetic rubber. On the other hand, it is fair to observe that there is little evidence in the data to suggest that prices for synthetic rubber (the only price data available) are sensitive to demand conditions.

Another simplification is the use of GDP growth rates in OECD countries to reflect market conditions. While income growth in these countries was an excellent indicator of demand conditions over the period covered by the historical data available [see Grilli et al (1980, p 77)], economic conditions in other groups of countries--particularly the high income developing countries--will by all accounts be extremely important in the future. While this fact does not call into question the specification in Equation (3), it does suggest the need for caution in using Equation (3) to forecast future natural rubber prices.

The use of time as a proxy for technical change, and economies of scale and learning also warrants comment. While time is probably as good a proxy as can be found for technical change, one might well consider using cumulative output as a proxy for economies of learning, and output as a proxy for economies of scale. This specification was in fact considered and rejected on two accounts. First, time, output, and cumulative output are highly collinear. It is impossible to disentangle econometrically the effects of each of these variables. Second, given the need to choose between explanatory variables, we opted for the one that is not influenced by price--time. This greatly simplifies the econometric structure of the model and facilitates its use for price forecasting. The cost of this [unavoidable] simplification may, of course, be some specification error.

c. Estimation

Given the objective to obtain plausible conditional forecasts of natural rubber prices, the above model can be further simplified prior to estimation. Specifically, Equation (2) may be substituted into Equation (3), obtaining an equation that explains natural rubber prices as a function of a time variable, OECD countries' GDP growth rate, and the price of crude oil. This equation is shown as equation (4) below.

$$(4) \quad pnrub_t = c_0 + c_1 \, time + c_2 \, ggdp_t + c_3 \, poil_t$$

This is the form of the model that is estimated empirically. Based on the discussion above, it should be expected that the estimated value of $c_1$ would be negative, and the estimated values of $c_2$ and $c_3$ would be positive.

Equation (4) was estimated by ordinary linear regression methods using the data reported in Table 1. These data include average annual prices in New York [cif] of Ribbed Smoked Sheet 1 in 1977 US cents, average annual prices of Saudi light crude [fob Ras Tanura] in 1977 dollars, and GDP growth rates for the OECD countries. The data cover the period 1963-1977.

TABLE 1

MODEL DATA SET

| Year | Natural Rubber Price (cents/kg) | Crude Oil Price ($/bbl) | OECD GDP Growth Rates (%) |
|---|---|---|---|
| 1963 | 150.5 | 3.7 | 4.8 |
| 1964 | 143.1 | 3.4 | 6.2 |
| 1965 | 141.0 | 3.2 | 5.3 |
| 1966 | 128.4 | 3.2 | 5.6 |
| 1967 | 106.6 | 3.2 | 3.8 |
| 1968 | 113.7 | 3.4 | 6.0 |
| 1969 | 148.2 | 3.4 | 5.2 |
| 1970 | 106.9 | 3.0 | 3.6 |
| 1971 | 85.1 | 3.6 | 3.6 |
| 1972 | 77.5 | 3.7 | 5.6 |
| 1973 | 125.6 | 4.3 | 6.4 |
| 1974 | 110.0 | 12.6 | 0.1 |
| 1975 | 73.0 | 11.9 | -0.6 |
| 1976 | 95.7 | 12.6 | 5.6 |
| 1977 | 91.7 | 12.4 | 4.0 |

Sources:
Rubber Prices-Commodity Trade and Price Trends (1978 edition) Report No. EC-166/78, World Bank, p 82
Oil Prices-Commodity Price Forecasts, May 1979, World Bank
OECD growth rates - OECD

The results of the estimation of equation (4) are reported in Table 2. Column 1 of the table lists the explanatory [i.e. right-hand-side] variables appearing in equation (4). Column 2 reports the estimated coefficients associated with each of these variables. Each coefficient may be interpreted as giving the effect of a one unit increase in the corresponding explanatory variable on the real price of natural rubber. For example, it can be seen by examining the coefficient of the time variable that the real price of natural rubber, other things being equal, fell by an average of approximately five-and- one-half cents per kilogram per year. All estimated coefficients have the expected sign.

Table 2

Results of Ordinary Least Squares

Estimation of Model 1

| Variable | Coefficient | Standard Error | Significance |
|---|---|---|---|
| cons | 121.7420 | 18.8260 | 0.00002 |
| time | -5.5081 | 1.6696 | 0.0035 |
| ggdp | 4.2314 | 2.7415 | 0.0755 |
| poil | 2.9218 | 2.0466 | 0.0906 |

$R^2$(adjusted for degrees of freedom) = 0.6453 (0.5486)
F(3,11) = 6.6710
Durbin-Watson statistic = 2.0056
Standard error of estimate = 17.2331

Column (3) of the table reports estimated standard errors corresponding to each coefficient reported in column (2). For example, the standard error of the estimated coefficient of the time variable is 1.67.

Column (4) reports the significance levels of each of the estimated coefficients. These significance levels are based on application of the one-tailed t-test. As can be seen from the table, all coefficients are significant at approximately the ten-percent level or better.

Overall, the results reported in Table 2 are satisfactory. The estimated equation provides a reasonable fit to the data. It explains approximately 65 percent of the variance in the data (note that $R^2$ is 0.6413) and that the standard error of estimate of the equation (i.e., 17.23) is about 13 percent of the mean rubber price. The Durbin-Watson statistic is consistent with the hypothesis of no first order serial correlation in the error term.

## 4. FORECASTS

Forecasts of future real prices of natural rubber may be obtained with the aid of the model estimated in the preceding section simply by making assumptions about future values of model coefficients and/or future values of the model's explanatory variables. Five alternative forecasts computed according to this procedure are presented in Table 3.

Forecast A assumes that real GDP in the OECD countries grows at 4 percent per year, that real oil prices increase at a rate of 3 percent per year, and that the downward trend in prices due to technical change and/or scale economies continues at the same rate that it did over the period 1963-1977. As can be seen by examining Forecast A, real price declines from 149.8 cents per kg in 1984 to 140.0 cents per kg in 1995. Thereafter, price increases to 144.8 cents per kg by the end of the period considered. The price decrease in the early years results from the fact that the time trend effect more than offsets the effect of increasing real oil prices. In the latter part of the period (i.e. after 1995) the effect of increasing real oil prices predominates.

Table 3

Forecasts of the Real Price of Natural Rubber

(1977 US cents/kg)

| Year | A | B | C | D | E |
|---|---|---|---|---|---|
| 1984 | 149.8 | 149.8 | 141.5 | 145.6 | 145.6 |
| 1985 | 148.4 | 153.9 | 141.1 | 140.1 | " |
| 1986 | 147.0 | 158.0 | 138.7 | 134.5 | " |
| 1987 | 145.6 | 162.2 | 137.3 | 129.0 | " |
| 1988 | 144.5 | 166.6 | 136.2 | 123.5 | " |
| 1989 | 143.4 | 171.0 | 135.1 | 118.0 | " |
| 1990 | 142.6 | 175.7 | 134.3 | 112.5 | " |
| 1991 | 141.8 | 180.5 | 133.5 | 107.0 | " |
| 1992 | 141.0 | 185.2 | 132.7 | 101.4 | " |
| 1993 | 140.5 | 190.2 | 132.2 | 95.9 | " |
| 1994 | 140.3 | 195.5 | 132.0 | 90.4 | " |
| 1995 | 140.0 | 200.7 | 131.7 | 84.8 | " |
| 1996 | 140.1 | 206.4 | 131.8 | 79.3 | " |
| 1997 | 140.2 | 212.0 | 131.9 | 73.8 | " |
| 1998 | 140.6 | 217.9 | 132.3 | 68.3 | " |
| 1999 | 140.9 | 223.7 | 132.6 | 62.7 | " |
| 2000 | 141.6 | 230.0 | 133.3 | 57.3 | " |
| 2001 | 142.5 | 236.4 | 134.2 | 51.7 | " |
| 2002 | 143.5 | 242.9 | 135.2 | 46.2 | " |
| 2003 | 144.8 | 249.7 | 136.5 | 40.7 | " |

Assumptions

A: ggdp = 4 percent. Real oil price grows at 3 percent per year. Continuation of time trend.

B: ggdp = 4 percent. Real oil price grows at 3 percent per year. Time trend ceases.

C: ggdp = 2 percent. Real oil price grows at 3 percent per year. Continuation of time trend.

D: ggdp = 2 percent. Real oil price constant. Continuation of time trend.

E. ggdp = 2 percent. Real oil price constant. Time trend ceases.

Forecast B differs from Forecast A in that it is assumed that the time trend effect does not operate. This might happen, for example, if the technical and scale effects that were important in the pre-1970 period have in fact been played out, as claimed by Allen (see Section B). As can be seen by comparing A and B, cessation of the trend effect would have an enormous impact on future natural rubber prices, other things being equal. Real prices, according to Forecast B, would increase by about 70 percent over the period.

Forecast C assumes that the rate of growth of real GDP in the OECD countries is 2 percent per year, that real oil prices increase at 3 percent per year, and that trend effects continue. The real price forecast in this case is uniformly 8.3 cents per kg lower than it is in A.

Forecast D assumes that the rate of growth of real GDP in the OECD countries is 2 percent per year, that real oil prices are constant, and that trend effects continue. As can be seen, the combined effect of these assumptions is a continuous decrease in price, with price falling to less than one-third of its initial value.

Forecast E is based on the same assumptions as Forecast D except that it is assumed that the trend effect ceases. The result is a forecast that the real price of natural rubber would be stable at a value of 145.6 cents per kg.

A comparison of Forecasts A-E underscores the importance of the future trend effect. If it has indeed been played out, as suggested by Allen, then one might anticipate a future in which real natural rubber prices either remain roughly constant or trend strongly upward. This appears as though it would be true for plausible ranges of world economic growth and growth in the real price of oil.

Additional factors that would tend to reduce the size of any trend effect in the future include mounting concerns about the environmental effects of synthetic rubber production, and concerns about occupational exposures to certain of the basic chemicals employed in common synthetic rubber production processes. Grilli et al (1980, p 93) note that

> The cost of pollution control systems is expected also to increase substantially the unit cost of SR. Finally, the potential health problems related to prolonged exposure to chemicals, such as benzene, are now being investigated in the United States and elsewhere. This will likely increase worker and government concern over the safety of some synthetic rubber production processes, thereby increasing the uncertainties connected with planning new production capacity.

If the trend effect continues at the same strength that it exhibited in the period covered by our statistical analysis, future natural rubber prices will be strongly affected by economic growth and the growth of real oil prices. If the latter rates are reasonably high, real natural rubber prices do not, in our forecasts, exhibit significant trends. If the latter rates are low, however, real natural rubber prices could collapse.

The combinations of circumstances reflected in the assumptions underlying forecasts A through E are not equally likely. For example, combinations of assumptions with relatively low GDP growth rates (of 2 percent per year) and relatively high rates of increase in oil prices are probably less likely than combinations of relatively high growth rates. This is because low rates of GDP growth would tend to restrain oil price increases. Similarly, we would expect to see continuation (or perhaps even intensification) of the time trend effect associated with relatively high rates of increase of real oil prices, reflecting correspondingly intense R&D efforts aimed at improving the efficiency of synthetic rubber production. Based on these considerations, forecasts A, B, and E would, on balance, be more probable than would C and D.

It must be stressed that the simple structure of the model formulated and estimated in Section 3 does not permit direct investigation of the effect of many factors that could be important in the future. It does not, for example, permit direct calculation of the effects of possible increases in the yield of rubber from hevea or expansion of the land area planted in hevea. Neither does it permit direct calculation of the effect of possible large-scale initiation of guayule rubber production. Both of these possibilities could result in material increases in the supply of natural rubber, with attendant restraining effects on the price of natural rubber. The qualitative model developed in Section 2 clearly shows that when natural rubber supply becomes large relative to rubber demand, synthetic rubber prices may no longer provide an effective floor to the market. In such circumstances, the price forecasts produced by a model that presumes such a relationship between synthetic and natural rubber prices (like that developed in Section 3) would be too optimistic.

What can be said of these possibilities? In this context, the analyses by Foster et al (1980) and Grilli et al (1980) comparing potential natural rubber demand to potential natural rubber supply are most useful. Both analyses conclude that there will be a shortfall between potential supply and potential demand. In such an environment, the basis for making a relatively optimistic price forecast (such as forecasts A, B, and E above) is strengthened.

## 5. CONCLUSIONS

On the basis of the above analysis, it appears warranted to conclude that future real natural rubber prices will tend to rise. Forecasts A, B, and E presented in the last section cover a reasonable range of possibilities. Moreover, these forecasts are consistent with the conclusion reached by Grilli et al (1980, p 92) concerning the market outlook for natural rubber.

> On the whole, the natural rubber industry is facing favorable prospects for growth. Its market potential is probably greater than at any time in the past twenty years. The quadrupling of the real price of crude oil between 1973 and 1979 has enhanced considerably the competitive position of natural rubber in the short-term, and its long-term competitiveness appears to have been strengthened even further.

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