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SOCIAL RETURNS FROM RUBBER RESEARCH

IN PENINSULAR MALAYSIA

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SOCIAL RETURNS FROM RUBBER RESEARCH
IN PENINSULAR MALAYSIA

By

Teck Yew Pee

A DISSERTATION

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ABSTRACT

SOCIAL RETURNS FROM RUBBER RESEARCH
IN PENINSULAR MALAYSIA

By

Teck Yew Pee

This study attempts to quantify social returns from rubber research in Peninsular Malaysia, one hundred years after natural rubber, Hevea brasiliensis, was introduced and more than fifty years after systematic rubber research began in the country.

The specific objectives of the study are: (1) to document the evolution of rubber research in Malaysia; (2) to test the consistency of the Malaysian experience in rubber and rubber research with the "induced development model"; (3) to estimate the social returns from investment on rubber research; (4) to evaluate the distribution of research benefits between the two rubber producing subsectors and between different factors of production; and (5) to assess the extent of secondary benefits generated by the rubber industry.

Documentation of the evolution of private and governmental rubber research in Malaysia provided some historical evidence to show that the Malaysian experience of using rubber research as a development strategy was consistent with the "induced development model" of Hayami and Ruttan.

The methodological framework used in measuring returns from investment on rubber research was the direct benefit cost or index number approach. To estimate gross benefits use was made of the "economic surplus" concept. Data required included price elasticities of supply and demand, the shift factor, k, rubber prices, and a deflator. It was also deemed necessary to treat the two producing subsectors, estates and smallholdings, separately because of differences in their organization and mode of production.

The items in the cost stream included all expenditures incurred by the RRIM, Prang Besar, and other private research stations, as well as the cost of the post-War rubber replanting scheme. To take only the direct cost of breeding and selection would give a distorted picture of the nature of the rubber research process.

The efficiency of Malaysian investment on rubber research was assessed by bringing together the benefit and cost streams through the use of three common investment criteria: benefit cost (B/C) ratio, net present value (NPV), and internal rate of return (IRR).

The computations indicated that the overall direct primary returns to producers and consumers from rubber investment are high, with IRRs of 24-25 percent. The rates are comparable to those obtained in earlier studies which were mostly based on annual crops. Moreover, some of the earlier studies, apparently, took account only of the direct cost of the breeding program.

When research benefits received by producers in Malaysia alone were included in the computations the IRRs, about 12 percent, were still greater than the 10 percent opportunity cost of capital in Malaysia. Subsequent sensitivity tests to correct for probable

downward biases in the yields of unselected materials, and for possible overestimation of research benefits, showed no significant differences between the rates obtained. It was, therefore, concluded that even if secondary benefits were excluded, the primary benefits to producers were high enough to warrant Malaysian investment on rubber research.

Consideration of the distribution of producer benefits between estates and smallholdings revealed that estates have been the major beneficiaries of rubber research. This can be chiefly attributed to the lag in the rate of replanting by the smallholding subsector.

While the evidence on the distribution of producer benefits between different factors of production is too meager to afford firm conclusions, the tentative conclusion is that landowners, as a group, have benefitted more than the workers.

The main secondary benefits generated by the rubber industry is in the form of intangibles, through eradication of diseases and provision of health and medical services to estate workers.

To

My Father and the Memory of my Mother

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CHAPTER I

INTRODUCTION AND BACKGROUND

This study attempts to quantify social returns from rubber research in Peninsular Malaysia, one hundred years after natural rubber, Hevea brasiliensis, was introduced and more than fifty years after systematic rubber research began in the country. A number of previous studies have shown that the returns from investment in agricultural research, both in developed and developing countries, were uncommonly high. These studies also drew attention to the underinvestment in agricultural research by developing countries and the potential dividends from increasing investment on research in these countries.

Malaysia's apparent ability and success in utilizing science and technology in rubber research as a development strategy--a strategy more commonly associated with a developed country--therefore, deserves attention. It can provide an object lesson for other developing countries that may be contemplating investing in agricultural research or induce them to expand their research facilities.

To set the stage and lend perspective to the study, this chapter will provide background information on the early history of rubber, the dominance of Hevea brasiliensis as the principal plantation crop, the development of the industry, rubber restriction and replanting schemes, the contribution of rubber to the Malaysian economy, as well as the organization of rubber research. Besides adding breadth to the study, the historical background can serve as a reference point against which subsequent developments in the industry can be clarified.

Early History of Rubber

Since the history of rubber has already been given in detail by a number of writers only a brief outline will be given here.[1]

Initially the use and knowledge of rubber was confined to localities where the wild rubber-producing plants were found. Despite its discovery by Columbus and later Spanish explorers in the fifteenth and sixteenth centuries, rubber was unknown to Europeans until the astronomer de la Condamine sent samples of a mysterious elastic substance or "caoutchouc" back to France from Peru in 1736. Interest was aroused following de la Condamine's report, which contained detailed descriptions of the trees, the native methods of collection, their procedures for processing, and his estimate of its possible uses. Expeditions were soon sent to French colonies as well as to the original Spanish sources. The samples that were brought back showed much diversity in their resin content and elasticity. It was only many years later that it was established that there were in fact several species of *Hevea*.

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[1]For details, see P. Schidrowitz and T. R. Dawson, ed., *History of the Rubber Industry* (Cambridge, 1952); A. McFadyean, ed., *The History of Rubber Regulation, 1934-43* (London: George Allen and Unwin, 1944); L. G. Polhamus, *Rubber: Botany, Production and Utilization* (London: Leonard Hill, 1962); and J. M. Drabble, *Rubber in Malaya 1876-1922: The Genesis of the Industry* (Kuala Lumpur: Oxford University Press, 1973).

With the beginning of the nineteenth century, many species of plants were known to produce latex capable of being coagulated and used for similar purposes as Hevea rubber, such as Ficus elastica Roxb., Castilloa elastica Carv., Funtumia elastica Stapf., Willuughbeia spp., Landolphia Palaqium gatta Burck, Payena spp., Mimusops balata (Aubl.) Goertn, Achras Zapota L., Manihot Glaziovii Muell Arg., and later Cryptostegia spp., Guayule (Parthenium argentatum Gray) and Solidago spp., among others.

It was not until the invention of the vulcanization process by Goodyear in 1839 that rubber moved into international trade channels as an economic product. The vulcanization process ranks as one of the major technological developments of the nineteenth century. The process, utilizing sulphur and crude rubber mixtures revolutionized the industry overnight since it was now possible for rubber goods to be produced which would overcome the deleterious qualities of the raw product. A long chain of technological advances in rubber manufacturing followed. However, the new industry received its greatest breakthrough when the pneumatic tire was invented by Dunlop in 1888 and tires were fitted to automobiles in 1895. Since that time the history and fortune of the rubber industry and the autombile industry have been closely interrelated. The major use of rubber has ever since been in the manufacture of automobile tires.

Prior to 1900 the entire world supply of rubber came almost exclusively from wild rubber trees. The Amazon basin of Brazil was the principal source. Much of the Brazilian rubber was derived from Hevea trees, of which brasiliensis is the most widely distributed.

Another important source of wild rubber from about 1890 was tropical Africa. The main producers were the French colonies in West Africa, and what were then the Belgian Congo and Portuguese Angola. The early sources of African rubber were almost entirely derived from vines belonging mostly to the genus Landolphia. These were almost invariably destroyed in tapping. Later the large forest tree Funtumia elastica or Kickxia was exploited for latex.

The only other major source of wild rubber was the guayule shrub in Mexico. It was only seriously exploited in the early years of the twentieth century. The rubber occurs in solid particles dispersed through the plant tissues and harvesting required the shrub being pulled up by the roots. Production declined rapidly after 1910 due to the dearth of new plants for harvesting. (With the onest of the "energy crisis" interest in the guayule has recently been revived in the U.S.)

Beginnings of Cultivated Rubber

The high prices for rubber in the mid-nineteenth century spurred the search for new supplies of wild rubber and the start of the systematic study of the bio-genesis, physiology, and ecology of rubber-bearing plants. It also encouraged attempts to cultivate rubber on a systematic scale.

The main initiative in the transfer of rubber from South America to the East came from the India Office in London. A member of the staff, Clements Markham, who had earlier organized the introduction of cinchona cultivation to India from Peru in the 1860s, is generally credited with the original concept. Since little formal knowledge existed about the varieties of rubber-yielding trees, their preferred habits, and the methods of extracting and coagulating the latex, James Collins, curator of the Pharmaceutical Society Museum, was commissioned to obtain information about the prospects of introducing rubber to the East. His report on "The Caoutchouc of Commerce" was submitted in 1872 and little time was lost in implementing its suggestions.

On the strength of Collin's report, the India Office attempted to obtain *Hevea* seeds through the British consul at Para, Brazil, but the main driving force leading to the first consignment of rubber seeds was Joseph Hooker, then Director of the Royal Botanical Gardens at Kew, near London.

A number of attempts were made to collect rubber seeds and plants from tropical America for dispatch to England. The first consignment of 2000 *Hevea* seeds obtained for Collins by a Mr. Farris in Brazil arrived in England and were sent to Kew for germination in June 1873. Only a dozen seeds germinated of which six were sent to the Botanic Gardens in Calcutta the same year, but the experiment was largely a failure due to adverse climatic conditions. In 1875, an organized attempt at collection was undertaken by Robert Cross, one of the quinine explorers, under commission by Markham. The species *Castilloa* was to be collected because of its greater latitudinal spread than the *Hevea* and also because it belonged to the family *Artocarpaceae* which was well represented in India. Cross brought back to Kew 7000 *Castilloa* seeds and numerous cuttings from the vicinity of the Chagres river in Central America. The following year he obtained 1000 *Hevea* plants together with a few of the *Ceara* variety. The *Castilloas* and *Cearas* were successfully established at Kew, and subsequently distributed overseas, but it is doubtful whether any of the *Heveas* survived the seedling stage to reach the East. The original records are conflicting but most scholars appear to credit Wickham's seeds as the starting point of the industry.

The "germ" of the industry was the seed obtained by Wickham in 1876, at the request of Joseph Hooker. Wickham collected some 70,000 seeds from the highlands between the Tapajos and Madeira rivers, where "the true forests" of *Hevea* were found. The seeds arrived at Kew in June 1876 and were planted the following day. Only 2,700 seeds germinated, less than 4 percent of the total. Owing to the lack of a suitable botanical garden in India, Hooker suggested that seedlings be sent to Ceylon (now Sri Lanka) for cultivation and subsequent distribution to Burma and other parts of the Indian Empire.

Over 1,000 seedlings were shipped from Kew to Ceylon in August 1876, and were planted out in the Botanic Gardens at Heneratgoda. Fifty plants were also sent from Kew to the Singapore Botanic Gardens which was founded in 1858 but this first consignment failed to survive. In June 1877, however, a second consignment of 22 plants was shipped from Kew to Singapore and were successfully established by the Superintendent of the Gardens, J. H. Murton. About half were planted in the Gardens on the edge of swampy ground, and a further nine were taken to Perak in Peninsular Malaysia, where they were established on well drained soil behind the house of the British Resident in the town of Kuala Kangsar. Although some uncertainty exists about the location of the remaining two plants, one is believed to have been planted at Durian Sabatang in the district of Telok Anson in Perak and the other in a nearby district also in Perak. These initial plantings, together with other trees grown in Ceylon from Wickham's seeds were the precursors of the Malaysian and Southeast Asian rubber industry. It is generally believed that seeds from the two centers at Singapore and Kuala Kangsar were responsible for the establishment of three quarters of the industry.

Although there were subsequent attempts at seed collection in South America, such as the *Hevea* seeds brought to Pasir Utjing estate in Java and a trade in *Hevea* seeds started by Scott Blacklaw in England in 1881, these had minimal effects on the development of the rubber industry in the East.

Dominance of Hevea Brasiliensis

The eventual emergence of cultivated *Hevea brasiliensis* as the dominant source of natural rubber and the geographic shift of the supply locus from South America and Africa to South and Southeast Asia was preceded by several decades of trial and errors in cultivating rubber-producing plants in many parts of the tropics. The Para rubber tree, *Hevea brasiliensis*, emerged as the premier cultivated tree for a number of reasons, including the following:

1. Of all the known rubber-bearing plants, *Hevea brasiliensis* gave the highest yield of latex over a sustained period. Moreover the acetone extract or resin content in the latex was very low--a desirable quality in latex;
2. The trees thrived on a wide range of soils in Southeast Asia where opportunity costs for land were low and accessibility was relatively high;

3. It proved remarkably resistant to both disease and insect pests. The acquisition of Hevea brasiliensis seeds from the upper reaches of the Rio Tapajos which were free of the South American Leaf Blight (SALB), Microcyclus ulei, endemic in South America, and relatively uncontaminated genetically by other species was fortuitous;
4. The invention of continuous "excision" tapping (see next chapter) by Ridley in 1889 and the relative ease of latex collection; and
5. The depredations of the coffee industry in Southeast Asia by coffee rust, Hemeila vastatrix. Rubber was widely planted in place of coffee, particularly in Peninsular Malaysia.

The shift from wild to cultivated rubber involved a dramatic geographical change in the locus of production. It also involved fundamental changes in the nature of factor inputs, factor proportions, and the organization characteristic of the productive process.

Rubber and Peninsular Malaysia

The introduction of rubber to Peninsular Malaysia in 1877 and the eventual spread of rubber planting from plantations or estates to smallholdings were instrumental in transforming a hitherto simple subsistence economy into a multi-racial society and an economy possessing "a complex of economic facilities of exceptional potency --an established transport and communication system, a stable currency, an expanding educational system, widespread banking facilities, and a relatively skilled labor force which has grown within a framework in which entrepreneurial abilities have loomed large."[2] (Estates are defined as producing units with 100 acres or more each and operating their own set of accounts, while units of less than this size are smallholdings.)

Development of the Industry

The policy of the British colonial administration during the early years following the introduction of rubber was to encourage the expansion of rubber growing along "scientific lines" by European planters, and active discouragement of the spread of commercial attitudes among Malay farmers whose traditional mainstay had been padi cultivation. In pursuance of this policy, land rents and land use policy were manipulated in favor of estate development.[3]

Rents on land planted by smallholders were pegged at almost twice the level for estate land.[4] Additionally, certain categories of land alienated to smallholders could not be planted with rubber by the imposition of "no rubber" conditions on them. This was done, ostensibly, to prevent the dispossession of such land by estate interests. The real objective appeared to be otherwise. Lands on which rubber planting was forbidden by official fiat were subject to very low rents

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[2] Norton Ginsburg and Chester F. Roberts, Jr., Malaya (Seattle, 1958), p. 366.

[3] P. Radhakrishnan, "The Role of Rubber in the West Malaysian Economy" (Ph.D. dissertation, Stanford University, 1974), p. 43.

[4] T. G. Lim, "Peasant Agriculture in Colonial Malaya" (Ph.D. dissertation, Australian National University, 1971), p. 123.

but the premium was raised if this condition was violated. This policy eventually led to Malay reservations and the Rice Land Enactment of 1917 to forestall further displacement of rice land by rubber planting.

Land was, however, made available to estates on very liberal terms.[5] This prompted the newly-established rubber companies to acquire more jungle land than they could develop at the time acquisition was made. (These reserves of jungle land, however, enabled estates to expand unfettered when restrictions on land alienation were later imposed.)

To further encourage estate development, financing was provided through a "Loans to Planters" Scheme, which was set up by the government in 1904 with an initial fund of half a million dollars. It was imported capital from the London market, however, which provided the real stimulus to estate expansion. European planters early came to recognize that the only practical means of advance was to harness capital from abroad through the medium of corporate ownership.

The "instrument" by which capital from the London market was channelled to Malaysia was the established British merchant houses in Singapore. Merchant houses such as Harrisons and Crosfield, Guthrie and Company, Edward Boustead and Company, Barlow and Company, etc., had been actively engaged in the export trade of the Malay archipelago for many decades prior to the introduction of rubber. They had built up a reputation for financial integrity, maintained close contact with

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[5]Quit rent was only ten cents per acre for the first ten years, after which the rent was raised to fifty cents per acre--see J. C. Jackson, Planters and Speculators (Kuala Lumpur: University of Malaya Press, 1968), p. 220.

the European planting community, had access to government officials, and were well acquainted with general economic conditions in Malaysia.

It was to the large merchant houses which bought their produce and supplied their input requirements that European planters turned to for capital to expand their operations when rubber prices started to rise from 1905. They were eminently suited in the role of intermediaries between British investors, on the one hand, and European planters, on the other.[6]

Initially, the inflow of capital from the London market was mainly used to acquire European proprietary estates. Later the funds were used to buy up land already planted up with rubber by Chinese and Malay planters, and to open up jungle land.

In the process, the merchant house or "agency house," as they are now more popularly known, was usually appointed the secretary of a company in London and managing agents for the associated estate in Malaysia.[7] As managing agents they were responsible for hiring competent estate managers and providing them with general supervision and technical advice, supplying the inputs required by the estate, marketing the rubber produced and ensuring that proper accounts were kept. For these services, the agency house received a fee on the acreage

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[6]From 1909, a "classical" rubber boom led to a mad scramble for rubber shares by British investors, and resulted in the formation of dozens of new rubber planting companies.

[7]The responsibilities of a company secretary involved maintaining share registers, arranging meeting of company directors, and ensuring the fulfillment of all legal obligations by the company. Frequently, the agency house would even hold shares in the companies they manage. For a concise account of agency houses in Malaysia, see J. J. Puthucheary, Ownership and Control in the Malayan Economy (Singapore: Eastern Universities Press, 1960).

managed and a commission on the inputs supplied and the rubber marketed.

Apart from capital, labor too had to be imported. The country, then, was sparsely populated and Malays were generally averse to working on the estates. Labor was imported from India, China, and to a lesser extent, Java. As European planters were more used to and preferred Tamil laborers, an efficient system for their importation from South India was set up under the Indian Immigration Committee.

Although cultivated rubber was initially synonymous with estate rubber, it was soon discovered to be an "ideal" smallholder crop.

Some of the factors that led to the adoption of rubber by smallholders were (1) the tree fitted easily and naturally into the _kampung_ (village) setting with its emphasis on tree crops; (2) rubber cultivation required relatively little labor or capital; (3) rubber seeds were readily available to the grower after 1910; (4) an abundance of land, at least initially; and (5) the rapid ease in acquiring the basic tapping and processing skills. The tree is, moreover, non-seasonal and the labor involved in tapping could be spread over the year without clashing with the labor requirements for the seasonal padi crop.

Consequently, even when government policy favored his exclusive attention to padi production, the Malay peasant showed greater economic rationality in moving to rubber for the comparative advantages of rubber over padi growing were often as high as 100 percent.[8]

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[8] P. T. Bauer, _The Rubber Industry: A Study in Competition and Monopoly_ (London: Longmans, 1948), pp. 60-63.

Despite official attempts to restrict their participation and the highly discriminatory treatment accorded them under two rubber restriction schemes (see next section for more details), smallholders showed their resilience by managing to grow at about the same rate as the estate subsector during most of the pre-World War II period. By 1940, smallholders accounted for about 1.3 million acres or just under 40 percent of the total planted area under rubber, and about the same percentage of total rubber production.

The respective shares of the two subsectors in terms of both acreage and production have undergone considerable change since the War. Although the estate subsector's share of the total rubber area decreased from 61 percent in 1940 to 35 percent in 1973, estates still produced 46 percent of total rubber production in 1973. Estate production actually increased by about 50 percent between 1940 and 1973. Over the same period, the smallholding acreage increased from 39.1 percent to 65 percent of the total planted acreage. The increase in the output of smallholdings over the same period was not, however, commensurate with the increase in acreage. In 1973, the smallholding subsector's output was only 54 percent of total rubber output. As will be seen in a following section, the divergence in productivity between the two subsectors can be attributed to the earlier adoption of high-yielding materials by the estate subsector and past neglect and discrimination against smallholders.

Rubber Restriction Schemes

The extreme instability of rubber prices was demonstrated early after the establishment of the industry. Prices which had risen

steeply from 1905 dropped heavily between 1910 and 1914. The instability of prices became even more pronounced during the period between the two World Wars. Thus it was that the industry found itself involved in organized restriction schemes of a kind usually associated with industries in decay. The two major restriction schemes: the Stevenson Restriction Scheme of 1922, and the International Rubber Regulation Agreement (IRRA) of 1934, were imposed following the onset of the slump of 1920 and the Great Depression of 1929.[9] The Stevenson Restriction Scheme affected only rubber producers in the two British rubber producing territories of Malaysia and Ceylon.[10] The signatories to the IRRA were the UK, Holland, France, and Thailand, who jointly controlled 98 percent of the area under rubber. The imposition of rubber restriction was strongly advocated by estate interests through the RGA.

The stated aim of both restriction schemes in curtailing output was to raise rubber prices. While this object was partially achieved in the short run, the measures adopted helped to preserve inefficient producers, stifled the growth of the nascent smallholding subsector,

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[9] The restriction schemes have been described in detail in a number of studies: A. McFadyean, ed., The History of Rubber Regulation, 1934-43 (London: George Allen and Unwin, 1944); K. E. Knorr, World Rubber and Its Regulation (Stanford: Stanford University Press, 1945); C. R. Whittlesey, Government Control of Crude Rubber (Princeton: Princeton University Press, 1931); J. W. F. Rowe, "Studies in the Artificial Control of Raw Material Supplies: Rubber," Royal Economic Society Memorandum No. 29 (London, 1931).

[10] The RGA was founded in 1907, with headquarters in London, and essentially comprised the sterling rubber companies, i.e., companies incorporated in the UK, operating in Malaysia, Ceylon, and Indonesia.

curtailed the growth of new capacity, and stimulated the search for new rubber substitutes.

It is now generally conceded that smallholders in Malaysia and Indonesia, particularly those in Malaysia who bore the brunt of both restriction schemes, were grossly discriminated against over both quota allocations and new planting. A fair allocation would have been based on the proportion of the mature area occupied by each subsector, and on the average yields obtained per acre.

This procedure was not, however, used. Although smallholdings occupied about 38 percent and 40-42 percent, respectively, of the mature area during the period of the Stevenson Scheme and the IRRA, they were given not more than 34 percent and 38 percent of the "standard production" during the respective periods.

The dicrimination against smallholders in terms of yield was even more harsh. Sample surveys carried out by the Department of Agriculture in late 1921 found smallholding yields ranging from a low of 519 pounds per acre to a high of 1200 pounds per acre.[11] The latter figure is probably a gross exaggeration as it is known that yield per acre of unselected seedling trees rarely, on average, exceed 500 pounds.[12] During this early period all trees planted were unselected. However, because of their late start the trees on smallholdings were, on average, younger and were just reaching their peak yield (about ten

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[11]T. G. Lim, "Peasant Agriculture in Colonial Malaya" (Ph.D. dissertation, Australian National University, Canberra, 1971), p. 173.

[12]P. R. Wycherley, "Breeding of Hevea," Journal of the Rubber Research Institute of Malaya 21 (1969):38.

years from first tapping). Further, two other factors are germane to any discussion of yield differences between the two producing subsectors. One has to do with tree density or number of trees planted per acre. In general, the number of trees in tapping per acre on a smallholding can be twice the number on an estate. The other difference has to do with tapping intensity. Again, on most estates, the tapping system would be alternate daily, giving at most 160 tapping days per year. On smallholdings, on the other hand, the trees may be tapped daily for about 240 days per year. Thus it can be expected that, during this early period, yields on smallholdings would be higher than estates, on average.

In setting "standard production" on smallholdings and estates, the Stevenson Scheme administrators went against the available evidence. The maximum permitted standard production per acre of smallholding rubber was set at 320 pounds per acre. The standard production allowance for estates was initially set at 400 pounds per acre; later raised to 500 pounds per acre and completely removed on estates in May 1926.[13]

The pattern of overt discrimination against smallholders was carried over into the IRRA. Smallholders were discriminated against in two major ways: (1) underassessment of their productive capacity and (2) the almost complete ban on new planting.

The total loss to smallholders due to the underassessment of their productive capacity was estimated by Bauer to be in the region

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[13]C. R. Whittlesey, Government Control of Crude Rubber: The Stevenson Plan (Princeton: Princeton University Press, 1931), p. 65.

of $85 million.[14] But more important than the underassessment of smallholders' productive capacity were the impacts of government land policy and the planting provisions of the IRRA, which strengthened the competitive position of estates at the expense of the smallholders. From 1930-40, there was a complete ban on the alienation of new land for rubber planting and, with the exception of one year, 1939-40, the IRRA prohibited new planting on land already alienated for rubber planting. On the other hand, replanting was permitted.

The limitations on new planting were especially detrimental to smallholders, particularly of those with very small lots. In the absence of restriction, such producers with aging trees would normally have planted new land instead of replanting their existing holdings. Apart from the loss of income during the gestation period of six to seven years, replanting a small part of a two or three acre holding poses considerable technical problems. This was, however, largely academic since few, if any, smallholdings had reached a stage where replanting was necessary.

Estates, on the other hand, found the IRRA rules very conducive to replanting the lowest yielding fields with the high yielding planting materials that were becoming available, both locally and from Indonesia. When an estate replanted a certain portion of its area, the estate continued to receive 70 percent of the old assessment on the replanted area as a bonus toward the cost of replanting.[15] Yields

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[14] P. T. Bauer, "Malayan Rubber Policies," Economica 14 (May 1947):81-107.

[15] Ibid., p. 176.

from the new clones, which were typically double those of the earlier unselected seedling trees, contributed to substantial cost reduction on estates, thus enabling them to improve their competitive position vis-a-vis smallholdings.[16]

There can be, apparently, little doubt that from the social viewpoint of both consumers and producers the restriction schemes led to a net social loss.[17] The chief beneficiaries of restriction were the estates. The freezing of production distribution through quotas kept in being many inefficient producers and prevented any real stimulus to the reorganization and lowering of costs which subsequent developments have shown to be possible. Indeed, the fact that dividends from most company estate operations were remitted largely to shareholders in the UK, may well have nullified any immediate advantages even of this particular sector from the domestic Malaysian viewpoint.

The virtual freezing of the smallholding subsector at a time when smallholdings were expanding their rubber acreage faster than the estates prevented what might have been a great expansion of labor intensive production, with the concomitant benefits which would have

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[16]This should perhaps not be surprising since "one of the primary objectives of the Rubber Control Scheme was to protect European capital in the plantation companies in Malaya, Borneo, and the Netherland Indies from competition arising from the production of rubber by the natives at a fraction of the cost involved on European estates" in Rubber News Letter, September 30, 1936, p. 2 (quoted by Knorr).

[17]The restriction schemes appear to have had a pernicious effect on the efficiency of the Malaysian industry. When the Stevenson Scheme was lifted, Malaysia had to import bud sticks and selected seeds from Indonesia (see Allen and Donnithorne, 1957, p. 123).

accrued to the economy, particularly the rural sector. The restriction schemes are, therefore, open to criticism on general economic grounds as well as from equity considerations.

Further, the restriction schemes, undoubtedly, prompted the expanded production of substitutes for natural rubber, incurred the wrath of consuming countries, especially the U.S., and the establishment of new centers of production outside the regulated areas.[18]

Rubber Replanting

The other factor that contributed to the decline of the industry, particularly of the smallholding subsector, was the Japanese Occupation from 1942-45.

The rubber industry appeared at first impression to have emerged relatively unscatched from the rigors of the Occupation. Comparatively few trees, probably not more than 5 percent of the total planted area, were cut down to make way for food crops. However, the neglect of trees, mostly planted in 1915 or earlier, and the damage from warfare and looting to estate and smallholding property and equipment were more serious. The plight of the smallholdings, in particular, caused grave concern.

Fear that the main basis of the economy would be destroyed led to the setting up of a Rubber Smallholdings Enquiry Committee to look into the question of obsolescent trees on smallholdings. The Committee

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[18]The disruption of rubber supplies during World War I and the restriction under the Stevenson Scheme prompted the Ford Motor Company to plant rubber along the banks of the Rio Tapajos in Brazil. Ironically, though, the plantings of high yielding materials selected in Southeast Asia were destroyed by South American Leaf Blight (SALB).

found that in 1952, about 67 percent of smallholding trees were above 30 years (generally considered to be the economic life of a rubber tree).[19] The comparable figure for estates as at the end of 1953 was later estimated by the Mudie Mission to be 33 percent.[20]

To make matters worse, virtually the entire smallholding area was under low yielding or unselected trees. The Smallholdings Committee, therefore, warned that "the alternative to large scale replanting with high yielding material is the virtual extinction of the smallholder industry as it is known today."[21] At the same time, it was recognized that replanting with high yielding materials was the most efficacious way of reducing production cost and competing with synthetic rubber.

The gravity of the situation led the government to assume a direct (institutional) role to foster the requisite rate of replanting. A compulsory replanting cess (referred to as the Schedule II cess) was imposed in 1951 to finance replanting and combat the inflation generated by high rubber prices as a result of hostilities in Korea (the so-called Korean War Boom). In January 1952, an additional replanting cess (the Schedule IV cess) of 4.5 cents per pound was imposed on all rubber exported from the country. Money derived from

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[19] Federation of Malaya, Final Report of the Rubber Smallholdings Enquiry Committee (Kuala Lumpur: Government Printer, 1952), p. 12.

[20] R. F. Mudie, J. R. Raeburn, and B. Marsh, Report of the Mission of Enquiry into the Rubber Industry of Malaya (Kuala Lumpur: Government Printer, 1954), p. 68.

[21] Federation of Malaya, Final Report of Rubber Committee, p. 12.

the two cesses was channeled into two funds: Fund A for estates and Fund B for smallholdings, set up under the Rubber Industry (Replanting) Fund Ordinance, 1952. The Schedule IV replanting cess was refunded unconditionally to the estates but Schedule II was refunded only on proof of actual expenditure spent on replanting--introducing, thereby, an element of compulsion in the utilization of funds for replanting. The degree of compulsion on smallholders was absolute. Unless they replanted, smallholders would not obtain any financial repayment. A replanting grant of $400 per acre was paid in six installments to those whose work was approved by an official inspector. The scheme went into operation with effect from September 1952.

To coordinate all replanting on estates and smallholdings, the Rubber Industry (Replanting) Board was set up in 1953, and the grant for approved smallholdings was increased to $500 an acre. (The nucleus of the Replanting Board's staff was made up of smallholders advisory field staff seconded to it from the RRIM).

Although the notion of a cess to finance replanting had, apparently, originated from the estate subsector, estates now felt that they were overtaxed. Accordingly, the government in conjunction with the Rubber Producers Council (RPC), a body formed in 1951 to represent all sections of the industry, including the smallholdings, invited three British experts under the chairmanship of R. F. Mudie, to visit Peninsular Peninsula in 1954 and assess the issues of taxation and replanting in the rubber industry.

The Mudie Mission reviewed the precarious position of the industry and recommended an immediate acceleration of replanting to place the industry in a stronger competitive position with synthetic rubber by the early 1960s. It also called attention to the potential for the establishment of land development schemes to complement replanting on smallholdings, as well as proposing changes to the existing system of rubber taxes.[22]

On the basis of the Mudie Report, the government decided to set aside $280 million to subsidize estate and smallholder replanting. The estate subsector's share of the total grant was computed on the basis of total acreage. The government undertook to pay $400 toward the cost of replanting up to 21 percent of the total acreage of each estate.[23] On this basis the government's commitment to the estates amounted to $165 million. The allocation to smallholders was computed not on the basis of acreage but on the basis of the smallholder subsector's output relative to the estate subsector's output. On this basis, the smallholder subsector received only $112 million.

A second government grant was made in 1962; the allocation of this grant was made on much the same basis as the earlier grant. The estate subsector could replant up to 15 percent of their planted area from 1961 and received $112 million while the smallholding subsector received only $88 million. If the allocation to smallholders and estates had been made on the same basis, i.e., acreage, the

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[22]For an account of land development schemes in Malaysia, see S. C. Lim, "Land Development Schemes in West Malaysia: A Study of Benefits and Costs" (Ph.D. dissertation, Australian National University, 1972).

[23]The differential replanting grants to estates and smallholdings led some estate owners to subdivide their land into smallholding lots and by the process of registering different lots under different names they were able to qualify as smallholdings for the higher replanting grant. This process has been termed "pseudo subdivision"

smallholder subsector would have received $29 million more under the first grant and $24 million more under the second grant. Thus the method of allocating the government subsidy resulted in discrimination against smallholders and in favor of estates.

By the end of 1961 the estate subsector had used up all of the $168 million allocated to it under the first grant. Smallholders had only used up 40 percent of the first grant because most smallholder replanting in this period was financed out of Schedule II and IV cess revenues. Government assistance for estate replanting ended in 1968. By that time about 80 percent of the estate area was under high yielding rubber. With effect from 1973 only estates that have "satisfactorily replanted" with high yielding rubber are entitled to the refund of the monies from the replanting (schedule IV) cess credited to their account. Smallholders, however, will continue to receive replanting grants as before. The rates have been increased to $900 per acre for holdings below 5 acres from 1971.

General Features of Estates and Smallholdings

Mention has already been made that an estate is defined as a producing unit of greater than 100 acres, and that a unit of less than this size is a smallholding. This official distinction, however, masks a number of important differences between and within the two producing subsectors. Table 1 contains some salient features of the estate subsector. The table shows that the distribution of the 1908 estates in 1973, by size groups, is highly skewed. Almost two-thirds of the

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as there is no change in real ownership accompanying the change in legal ownership.

Table 1.--General Features of Estates in Different Size Groups--December 1973.

<table>
<tr><th>Size Group (Acres)</th><th>Total Planted Area ('000 acres)</th><th>Average Size (Acres)</th><th>Proportion High-Yielding Material (%)</th><th>Proportion Area Immature (%)</th><th>Average Area per Worker (Acres)</th></tr>
<tr><td>100-499</td><td>237.9</td><td>188</td><td>85.6</td><td>14.9</td><td>4.0</td></tr>
<tr><td>500-999</td><td>170.7</td><td>734</td><td>93.2</td><td>13.5</td><td>7.2</td></tr>
<tr><td>1,000-1,999</td><td>299.6</td><td>1,400</td><td>96.6</td><td>13.1</td><td>6.9</td></tr>
<tr><td>2,000-2,999</td><td>207.2</td><td>2,411</td><td>97.3</td><td>12.9</td><td>7.4</td></tr>
<tr><td>3,000-4,999</td><td>300.8</td><td>3,858</td><td>98.7</td><td>11.2</td><td rowspan="2">6.9</td></tr>
<tr><td>5,000 and over</td><td>239.6</td><td>6,476</td><td>95.0</td><td>18.0</td></tr>
<tr><td>All holdings</td><td>1,455.8</td><td>763</td><td>94.7</td><td>13.8</td><td>6.4</td></tr>
</table>

Source: Department of Statistics, Rubber Statistics Handbook, 1973 (Kuala Lumpur: Government Press, 1975).

total number of estates had less than 500 acres each, whereas, at the other extreme, 11 percent of the estates had more than 2000 acres apiece. In terms of total planted area, two-thirds of the estates in the smallest size groups had only 16 percent of the area, while 11 percent of the estates in the largest size groups occupied 51 percent of the area.

The proportion of high yielding materials planted on an estate is apparently also related to size. The estates in the largest size groups, which are predominantly foreign-owned, had relatively more of their area planted with high yielding materials.

General features of the estimated half a million odd smallholdings in 1972 are, similarly, presented in Table 2. As may be seen, individual holdings which are generally less than 10 acres apiece make up the biggest group, accounting for 64 percent of the total area. Holdings in land schemes and subdivided holdings occupy 22 and 13 percent, respectively, of the total area. Individual holdings are units which have been under individual or family ownership since their original alienation. Subdivided holdings are pieces arising from fragmentation of estates, a practice which first started in a big way in the 1950s. Holdings in land schemes can refer to both subsidized and unsubsidized schemes.

The proportion of high yielding materials planted in smallholdings also vary with the type of smallholding. With the exception of state schemes, holdings in land schemes have virtually all their land planted with high yielding rubber. In contrast, individual and subdivided holdings have a much smaller percentage of high yielding trees. Many of the individual holdings are very small (below 5 acres)

Table 2.--General Features of the Various Types of Smallholdings--1972.

Type of Holding	Total Planted Area ('000 Acres)	Average Size of Holding (Acres)	Proportion High Yielding Material (%)	Proportion Area Immature (%)
Individual	1712.4	6.4	63	25
Subdivided	359.4	9.9	64	31
In schemes:				
FELDA	188.2	9.1	100	52
Unsubsidized	131.7	5.9	88	27
Fringe alienation	128.7	5.4	95	52
State	36.1	4.4	73	38
FELCRA	24.0	5.4	100	100
Other subsidized	116.8	3.5	95	35
Total	2697.3	6.4	70	30

Sources: (1) Rubber Research Institute of Malaysia, 1973
(2) Federal Land Development Authority, 1973
(3) Rubber Industry Smallholders Development Authority, 1973

and serve as the only source of income for the owners. Despite the availability of replanting grants since 1952, many owners of individual smallholdings cannot afford to replant and forego income from rubber for the 6-7 year gestation period. This has elements of the "agricultural trap" in U.S. agriculture.[24]

Differences in organization and control between the two producing subsectors have been ascribed to the fact that plantation or estate agriculture is "a non-indigeneous transplant from the West."[25]

Foreign, particularly British but also American, French, Scandinavian, and Swiss, dominance of the estate subsector has long been a feature of the industry.[26] Before the Second World War the estate subsector, which was then the larger of the two subsectors, was virtually all foreign-owned. Even in 1973, the cut-off point of this study, at least 50 percent of the estate acreage was under foreign control.

The larger estates, which are mainly foreign-owned, are primarily owned by public and private joint stock companies, whereas most of the smaller locally owned (mainly Chinese-Malaysian) estates are sole proprietorships and partnerships.

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[24] G. L. Johnson and C. L. Quance, The Overproduction Trap in U.S. Agriculture (Baltimore and London: Johns Hopkins University Press, 1972), pp. 27-40.

[25] K. C. Cheong, "An Econometric Study of the World Natural and Synthetic Rubber Industry" (Ph.D. dissertation, University of London, 1972).

[26] As a direct result of this Malaysia is considered a "plantation economy" by G. L. Beckford, "The Economies of Agricultural Resource Use and Development in Plantation Economies," in Underdevelopment and Development: The Third World Today, ed. H. Bernstein (Penguin, 1976), p. 120.

The organizational structure of the larger estates is generally more complex and elaborate. Typically, each estate is a self-contained unit with its own resident labor force and administrative personnel. The close supervision of a large number of relatively unskilled workers is an integral part of estate production. This is achieved by means of an elaborate occupational hierarchy with clearly delineated lines of authority.[27] In addition to salaried resident managers and a hierarchy of subordinate staff these estates are almost always supervised and controlled by agency houses. The agency house system of management allows small companies to spread the costs of management and research over a large acreage. The agency houses maintain small groups of "visiting agents" or planting advisors who are responsible for transmitting technological advances (whether from their own research stations or those of other research organizations, private or public) to the estates under their control. This allows individual estates to adopt new technology rapidly, a factor of considerable importance in view of the highly capitalized nature of their investment.

The pattern of organization and control of smallholdings is rather different. Fewer inputs on a smallholding are monetized. Opportunity costs for both labor (mostly family labor) and land are consequently much lower, although over time capital intensification in smallholdings, particularly holdings in land schemes has been on the increase.[28]

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[27]Ibid.

[28]T. R. McHale, Rubber and the Malaysian Economy (Singapore: Malayan Publishing House, 1967).

There is apparently little or no foreign ownership of smallholdings. It was estimated on the basis of 1962 data that 68 percent of the operators on individual smallholdings were Malays and the remainder mostly Chinese. The comparable figures on land schemes were 74 percent Malays, 24 percent Chinese, and 2 percent Indians.[29]

Contribution of Rubber

The contribution of rubber to the economy has been significant and sustained over time. It has been estimated that rubber provided more than 75 percent of the total value of agricultural output in 1929.[30] If tin mining, the other "pillar" of the economy were included with the value of agricultural output, rubber's share would still be 59 percent. Even in the worst year of the Great Depression, 1932, when the price of rubber was only one-fifth of the 1929 level, rubber still accounted for 36 percent of the estimated total value of agricultural and mining output. In terms of export income, rubber was the source of about 38 and 24 percent of the country's total export revenue in 1929 and 1932, respectively. The contribution of rubber reached a peak about 1960 when more than 60 percent of the country's total export revenue and about 32 percent of the GDP were derived from it (see Appendix A, Table 1). In spite of its declining relative importance since then, as the economy has become more diversified, it remains the country's main supporting base, as may be seen in Table 3.

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[29] C. Barlow and C. K. Chan, "Towards an Optimum Size of Rubber Hodling," Journal of the Rubber Research Institute of Malaya 21 (1969): 613-53.

[30] Though the pre-War figures include Singapore (which was then part of British Malaya), it has never been a large producer of rubber.

Table 3.--Importance of Rubber to Peninsular Malaysia, 1973.

Economic Indicators	Total (Millions)		Rubber's Share (Percent)	
Gross Domestic Product, $		11,913.0		20
Gross Export Revenue, $		6,026.7		40
Planted Area, acres		4.2		55
Estates	1.5		20	
Smallholdings	2.7		35	
Labor Force, number		2.5		30

Sources: GDP: Treasury, Ministry of Finance. Economic Report, 1975.
GER: Department of Statistics, Monthly Statistical Bulletin, 1975
Planted Area: As for GER
Labor Force: Estimate base on C. Barlow and C. K. Chan, "Towards an Optimum Size of Rubber Holding," Journal of Rubber Research Instit. of Malaysia 21 (1969).

The table reveals that in 1973, the latest year for which complete figures are available, rubber still occupied 55 percent of the total cultivated area, contributed about 40 percent of total export revenue, 20 percent of GDP, and that a third of the country's working population was dependent on the industry.

The industry has also been an "efficient" earner of foreign exchange. This can be measured in terms of the net social gain to the economy contributed by the rubber industry. The net social gain from rubber exports is defined as the sum of the net value of foreign exchange earnings by rubber exports in a given period plus the net external effects associated with the export activity less the value of domestic resources used in producing it.[31] At market prices, each U.S. dollar's worth of free foreign exchange earned by the rubber industry was found to have cost the Malaysian economy approximately $2.70 in local currency between 1964 and 1968.[32] This compared very favorably with the exchange rate of $3.07 per U.S. dollar in 1964 and $3.08 per U.S. dollar in 1968. In both these years, the estate subsector was also the more efficient earner of foreign exchange.[33]

That rubber has remained the dominating force in the economy in spite of declining product prices, increasing input prices, and keen competition from synthetic rubber may be attributed in large part to the role played by research.

Organization of Rubber Research

To pay for research, a research cess was collected on every pound of rubber produced and exported from the country (see Table 7). In recent years income from this cess has amounted to about 0.3 percent of the country's GDP and about 1.5 percent of the value of rubber exports (Appendix A, Table 2). When it is realized that, on average, the developed countries devote about 2 percent and developing countries one-tenth of that figure or 0.2 percent of their GNP on all types of research activities, it is clear that Malaysia's relatively

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[31] S. R. Parson, Commodity and African Economic Development (Lexington, Mass.: Heath, 1974). For details of the procedure as applied to rubber, see P. Radhakrishnan, 1974.

[32] P. Radhakrishnan, "Role of Rubber in West Malaysian Economy," p. 131.

[33] Ibid.

massive investment on rubber research is unique for a developing country.[34] It has also been estimated that Malaysia alone undertakes about 85 percent of all research on natural rubber.[35]

The money collected through the research cess is administered by the Malaysian Rubber Research and Development Board (MRRDB) for disbursement to units under its aegis (see Figure 1). The Rubber Research Institute of Malaysia (RRIM) which was set up in 1925 is the main research arm of the MRRDB and, generally, receives more than half of the cess monies disbursed each year.

The RRIM is primarily concerned with the problems of the grower, and its work can be broadly divided between (a) research on the problems of production or production research, and (b) research on the product or what has come to be known as consumption or end-use research.

Production research is the responsibility of the Biological divisions: Botanical (now Plant Science), Soils (now Soils and Crop Management), and Pathological (now Crop Protection and Microbiology), and includes all problems in selection of land, preparation for planting or replanting, selection and proving of material, cultivation and manuring, tapping and collection--in fact every feature of rubber production up to the stage of latex collection. At this point, the Chemical Divisions (since 1971 enlarged to four Divisions: Applied

[34] I. Arnon, The Planning and Programming of Agricultural Research (Rome: FAO, 1975), p. 12.

[35] This estimate was made by L. H. N. Davis, Chairman of the Rubber Growers Association at the Association's meeting in London on June 21, 1976.

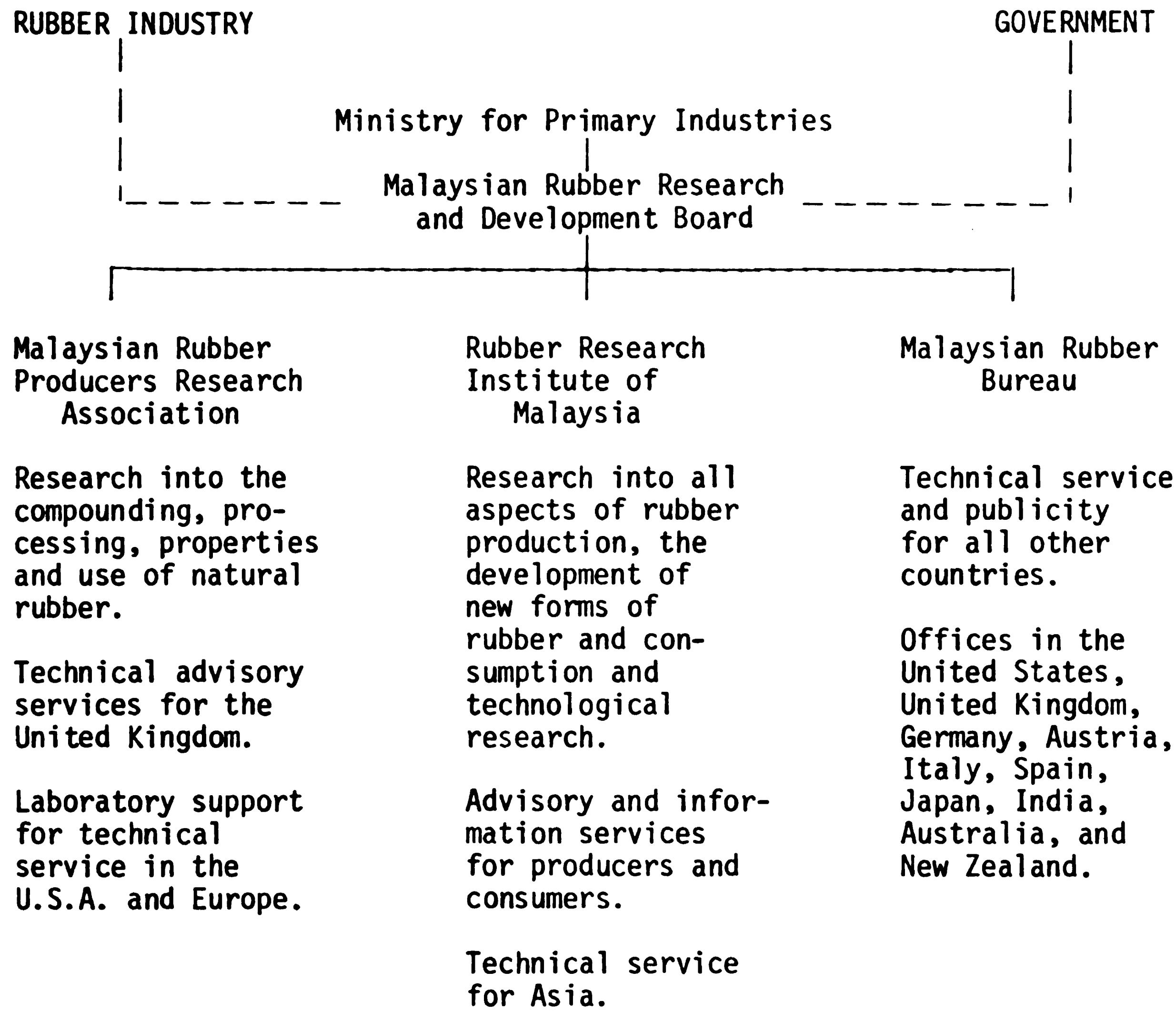

Figure 1. Research Network: Malaysian Rubber Research and Development Board.

Chemistry and Development, Specifications and Technology, Fundamental Chemistry and Physics, and Analytical Chemistry) take over and the chemists, engineers, and rubber technologists study means to improve the product, increase its range of uses, and generally endeavor to perfect the forms in which natural rubber is offered to the manufacturer. (This simple division of the research field is not so clearly defined in actual practice for part of the work of the last two named Chemical Divisions is on production related problems.)

Consumption or end-use research is the main responsibility of its sister organization, the Malaysian Rubber Producers Research Association (MRPRA), which is based in London. The main focus of this thesis will be on the work of the RRIM, however.

The cornerstone of research at the RRIM is on the breeding and selection of high yielding materials (clones and clonal seeds) to increase yield and lower cost per pound of rubber produced.[36] High yielding materials are conventionally defined as "All clonal seedlings and clones (budgrafts) approved by the Rubber Industry (Replanting) Board."[37] Under the enactment creating the Rubber Industry (Replanting) Board in 1952, the definition of high yielding materials is given as follows: "high yielding rubber means rubber grown from planting material which has been, or may from time to time be, recognized by the Rubber Research Institute of Malaya to be high yielding and which has been obtained from a source approved by the Board, or of which the

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[36] Planters Bulletin, No. 28 (1957), p. 1.

[37] This is the definition used by the Department of Statistics (see the Rubber Statistics Handbook).

Board may from time to time approve, after consultation with the said Rubber Research Institute."[38] In other words the RRIM is the final authority on what planting material can be classified as high yielding. The materials recognized by the RRIM as high yielding and suitable for large scale planting from 1939 onwards are given in Table 4. It is apparent both from the definition and table that the term high yielding material embraces a wide range of clones and clonal seedlings, including the earliest selected material planted some forty-five years ago to the most recently selected and proved material.

All other research and extension expenditures merely go to reinforce the basic work of breeding and selection. Unlike high yielding cereals, however, high yielding rubber is apparently not as responsive to other input packages. If rubber trees are well maintained and have no deficiencies of any kind, the maximum response in yield to fertilizer application is not expected to exceed 5 percent on mature trees.[39] In addition, "experiments show that improved methods of husbandry often do little more than modify by a fraction the yield level determined by the planting material . . ."[40] All this, notwithstanding, the entire spectrum of expenditures, including research (biological and chemical) and extension, incurred by the RRIM and other private research stations will be taken into account in this

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[38] Planters Bulletin, No. 32 (1957), p. 91.

[39] C. Iyer, Private communication, Rubber Research Institute of Malaysia, 1977.

[40] Wycherely, "Breeding of Hevea," p. 38.

TABLE 1. RRIM PLANTING RECOMMENDATIONS[2-16], 1939 – 73

Date	Recommendation					
	Class I		Class II		Class III	
	Clone	Seedling family	Clone	Seedling family	Clone	Seedling family
1939	Tjir 1 Tjir 16 PB 86 Pil B84 PB 25		Gl 1 Pil D65 Sab 24 AVROS 49 PB 186 Lun N BD 5	Tjir 1 selfed Tjir 1 × Tjir 16 Pil B84 × Pil A44 Pil A44 × Lun N AVROS 157 × AVROS 161 AVROS 166 × AVROS 161		
1946	Tjir 1 PB 25 PB 86 Pil B84 Gl 1		LCB 1320 PR 107 Pat 190 AVROS 255 AVROS 308 AVROS 352 AVROS 470 RRIM 501 RRIM 506 RRIM 509 RRIM 512 Lun N PB new clones	Tjir 1M PB 86M Pil A44 × Pil B84 PB ISG Ch ISG Batu Kawan Estate ISG Approved polyclone areas		
1952	Tjir 1 PB 86 RRIM 501 RRIM 513 Gl 1	PBIG/C PBIG/D PBIG/E Tjir 1M Tjir 1 illegitimate	RRIM 526 RRIM 527 LCB 1320 PR 107	Pil A44 × Pil B84 'Kupang mixed' seed		
May 1955	Tjir 1 PB 86 PR 107 RRIM 501 RRIM 513 Gl 1	PBIG/C PBIG/D PBIG/E Tjir 1M Tjir 1 illegitimate	LCB 1320 GT 1 RRIM 526 PB 5/51 PB 5/63	Ch IG/B Ch IG/E PBIG/F PBIG/G PBIG/H PBFP PBPP Seeds from boundaries of RRIM 501 AVROS 1571 BR 2 Pil B84 Tjir 1 PR 107 LCB 1320	RRIM 600 – 630 PB S78 PB T495 PB 9/82 PB 24/51 PB 23/27 PB 12/127 PB T157 PB T207 PB 28/83 PB 32/36 Ch 26 Ch 30 Ch 31 Ch 32 War A9 OY 1 IRCI 7 Nab 12 Nab 15 Nab 20	Illegitimate seedlings of high yielding clones
Jan. 1957	Tjir 1 PB 86 PR 107 RRIM 501 RRIM 513 Gl 1	PBIG/D PBIG/E PBIG/F PBIG/G Tjir 1M Tjir 1 illegitimate from approved areas	LCB 1320 GT 1 RRIM 519 RRIM 526 PB 5/51 PB 5/63	Ch IG/B Ch IG/E PBFP/A PBFP/B PBPP Seeds from boundaries of Tjir 1 AVROS 157 BR 2 Pil B84 RRIM 501 PR 107 GT 1 LCB 1320	RRIM 600 – 616 RRIM 620 – 630 PB T157 PB T207 PB T495 PB 9/82 PB 28/83 PB 28/59 PB 32/36 PB 12/127 PB 5/76 Ch 26 Ch 30 Ch 32 War A9 OY 1 IRCI 7 Nab 12 Nab 15 Nab 20	Illegitimate seedlings of high yielding clones
Jan. 1959	Tjir 1 PB 86 PR 107 RRIM 501 RRIM 513 Gl 1	PBIG/D PBIG/F PBIG/G PBFP/A PBFP/B Ch IG/B Ch IG/E Tjir 1M Tjir 1 illegitimate from approved areas	LCB 1320 GT 1 RRIM 519 RRIM 526 PB 5/51 PB 5/63 Ch 26	Seeds from boundaries of Tjir 1 AVROS 157 BR 2 Pil B84 RRIM 501 PR 107 GT 1 LCB 1320	RRIM 600 RRIM 603 RRIM 605 RRIM 606 RRIM 607 RRIM 610 RRIM 623 PB T157 PB T207 PB T495 PB 28/83 PB 28/59 PB 5/76 Ch 30 Ch 32 Nab 12 Nab 15 Nab 20 IRCI 7 OY 1 War A9 WR 101 PR 226 PR 228 PR 231 AVROS 427 AVROS 529 AVROS 1191 AVROS 1734 AVROS 1447 RRIC 6 RRIC 7 RRIC 22 RRIC 45 IRCI 2 IRCI 3 IRCI 6 IRCI 9 IRCI 10	Illegitimate seedlings of high yielding clones

					Class IIIA	Class IIIB (one task)
Jan. 1960	RRIM 501 removed from recommendations; no changes in Classes I and II					
Mar. 1961	GI 1 PB 86 RRIM 513 Tjir 1 PR 107	PBIG/F PBIG/G Ch IG/E Tjir 1 mother seed and other seeds from approved polyclone areas	GT 1 PB 5/51 PB 5/63 RRIM 519 RRIM 526 RRIM 605	PBIG/GG1 PBIG/GG2 Seeds from registered monoclone areas Seeds from boundaries of Tjir 1 AVROS 157 BR 2 Pil B84 RRIM 501 PR 107 GT 1 LCB 1320	RRIM 600 RRIM 607 RRIM 609 RRIM 623 RRIM 628 Ch 26 Ch 30 Ch 32 PB 5/76 PB 28/59 PB 28/83 AVROS 1734 IRCI 7 Nab 15 WR 101	RRIM 632 RRIM 638 RRIM 701 RRIM 707 Ch 148 Ch 153 PB 206 PB 213 PB 217 AVROS 427 AVROS 1191 AVROS 1447 AVROS 2037 IRCI 7 Nab 12 Nab 20 PR 228 PR 251 PR 252 RRIC 5 RRIC 7 RRIC 14 RRIC 45
Jan. 1962	No change	No change	RRIM 526 and PB 5/63 removed	Ch IG/F added to the PBIG/GG1 PBIG/GG2 Seeds from registered monoclone areas Seeds from boundaries of Tjir 1 AVROS 157 BR 2 Pil B84 RRIM 501 PR 107 GT 1 LCB 1320		
May 1963	PB 5/51 PR 107 RRIM 513 Tjir 1	PBIG/F PBIG/G PBIG/GG1 Tjir 1 mother seed and seeds from other approved polyclone areas	GT 1 RRIM 519 RRIM 600 RRIM 605 RRIM 607 RRIM 623 RRIM 628	PBIG/GG2 Ch IG/F Seeds from registered monoclone areas	AVROS 1734 Ch 30 Ch 32 Nab 15 PB 5/76 PB 28/59 PB 28/83	Ch 148 Ch 153 PB 213 PB 217 PR 228 PR 251 PR 252 PR 255 RRIC 5 RRIC 7 RRIC 45 RRIM 632 RRIM 636 RRIM 700 – 708 TR 3702
Jan. 1965	PB 5/51 PR 107 RRIM 513 RRIM 605 RRIM 623	PBIG/F PBIG/G PBIG/GG1	GT 1 RRIM 519 RRIM 600 RRIM 607 RRIM 628 RRIM 701	PBIG/GG2 Ch IG/F Seeds from registered monoclone areas	AVROS 1734 AVROS 1191 PB 28/59 PR 251 PR 253 PR 261 RRIC 7	Ch 153 Nab 17 RRIM 632 RRIM 703 RRIM 704 RRIM 705 RRIM 706 PB 213 PB 217
Jan. 1967	GT 1 PB 5/51 PR 107 RRIM 600	PBIG/GG1 PBIG/GG2	RRIM 519 RRIM 605 RRIM 607 RRIM 623 RRIM 628 RRIM 701 PB 28/59 PR 251 PR 261	Ch IG/F Seeds from registered polyclone, and other approved areas	Nab 17 PB 217 RRIM 703 RRIM 705 RRIM 706 RRIC 7 RRIC 36 PR 253 PR 255	AVROS 1350 Ch 153 PB 252 FS 9 RRIM 704 RRIM 709 – 714
Jan. 1969	GT 1 PB 5/51 PR 107 RRIM 600	PBIG/GG1 PBIG/GG2	RRIM 519 RRIM 623 RRIM 628 RRIM 701 RRIM 703 PB 28/59 PR 251 PR 255 PR 261	Ch IG/F PBIG/GG3 PBIG/GG4 PBIG/GG5 PBIG/GG6 Seeds from other registered areas	AVROS 2037 RRIM 705 RRIM 706 Nab 17 PB 217 PB 230 PB 235 PB 252 PR 253 RRIC 6 RRIC 36	AVROS 529 AVROS 1350 CISG 170 PR 228 RRIM 704 RRIM 709 – 719 RRIM 721 – 725
Jan. 1971	GT 1 PB 5/51 PR 107 RRIM 600	PBIG/GG1 PBIG/GG2	PB 28/59 RRIM 527 RRIM 623 RRIM 628 RRIM 701 RRIM 703 RRIM 519 AVROS 2037 RRIC 6 PR 251 PR 255 PR 261	PBIG/GG3 PBIG/GG4 PBIG/GG5 PBIG/GG6 Seeds from approved polyclone areas	AVROS 1328 AVROS 1350 Nab 17 PB 217 PB 230 PB 235 PB 252 PR 253 RRIM 705 RRIM 706	AVROS 529 CISG 170 PR 228 PR 258 PB 260 PB 262 PB 280 PB 281 RRIM 709 – 719 PB 721 – 725 RRIM 726 – 733
Mar. 1973	GT 1 PB 5/51 PR 255 PR 261 PR 107 RRIM 600	PBIG/GG1 PBIG/GG2	AVROS 2037 RRIC 6 PB 28/59 PB 217 PB 235 PB 252 RRIM 527 RRIM 623 RRIM 628 RRIM 701 RRIM 703	PBIG/GG3 PBIG/GG4 PBIG/GG5 PBIG/GG6 Seeds from approved polyclone areas	AVROS 1328 Nab 17 PB 230 PB 242 PB 255 PB 260 RRIM 712 RRIM 717 RRIM 722 RRIM 725	CISG 170 PB 243 PB 253 PB 254 PB 262 PB 274 PB 280 PB 281 PB 290 PR 294 RRIM 709 – 711 RRIM 713 – 716 RRIM 718 RRIM 719 RRIM 721 RRIM 723 RRIM 724 RRIM 726 – 733

thesis. (For more details of the rationale and procedure see Chapter IV.)

In general, about two-thirds of the RRIM's research expenditure is on biological research and one-third on chemical research, although since 1972 consumption research has been stepped up with the enactment of five new natural rubber Bills (see Chapter II). Moreover, the activities and finances of the RRIM "over a number of years shows that some 55 percent of total expenditure goes to research and 45 percent to advisory work to the growers."[41] In 1973, total expenditure in current dollars by the RRIM exceeded $18 million (Table 5).

Apart from the RRIM, a number of private organizations are also actively involved in some aspect or other of rubber research. In fact, as will be detailed later, breeding and selection work was largely spearheaded by the private sector in Malaysia and Indonesia. The major private research facility in Malaysia is at the Prang Besar Research Station. It was founded by Major Gough in 1919 for the purpose of clone selection and the creation of seed gardens, and is now under the control of Harrisons and Crosfield, the largest agency house in the country. Prang Besar has the distinction of having the longest uninterrupted record of rubber research in the country. The other private research establishments, such as Chemara (belonging to the Guthrie group), Dunlop, and Malayan-American Plantations (a subsidiary of the Unites States Rubber Company), are much smaller. Private research expenditures on rubber, mainly that of Prang Besar,

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[41] Planters Bulletin, No. 10 (1954), p. 2.

Table 5.--Composition of Research Expenditures by the Rubber Research Institute of Malaysia in Current Malaysian Dollars.

Year	Head Quarters			Experi-ment Station	Total RRIM Expendi-ture
	Staff Emoluments	Other Recurrent Expenditure	Total		
1925	1,300	2,091	3,391		3,391
1926	19,888	30,728	50,616		50,616
1927	137,242	112,156	249,398		249,398
1928	232,212	120,723	352,935		352,935
1929	234,364	109,344	343,708	59,801	403,509
1930	237,952	151,755	389,707	64,297	454,004
1931	246,225	155,470	401,695	70,042	471,737
1932	250,445	159,166	409,611	44,304	453,915
1933	189,591	144,694	334,285	33,648	367,933
1934	214,093	125,440	339,533	38,940	378,473
1935	188,708	166,160	304,868	59,014	363,882
1936	246,584	179,747	426,331	68,396	494,727
1937	288,299	207,306	495,605	102,759	598,364
1938	346,197	226,841	573,038	115,232	688,270
1939	335,048	222,827	557,875	119,739	677,614
1940	378,951	250,932	629,883	143,939	773,822
1941	394,887	217,401	612,288	180,315	792,603
1942-45	229,228	67,208	296,436	46,200	342,636
1946	463,272	231,407	694,679	234,444	929,123
1947	548,517	402,293	950,810	297,606	1,248,416
1948	868,239	606,109	1,474,348	345,805	1,820,153
1949	1,078,909	607,262	1,686,171	457,799	2,143,970
1950	1,128,450	749,369	1,877,819	415,062	2,292,881
1951	1,407,743	785,108	2,192,851	608,813	2,801,664
1952	1,610,614	1,133,463	2,744,077	586,895	3,330,972
1953	1,761,195	1,244,082	3,005,277	576,898	3,582,175
1954	1,816,512	968,295	2,784,807	541,910	3,326,717
1955	1,925,934	957,843	2,883,777	622,128	3,505,905
1956	2,105,688	1,226,124	3,331,812	712,447	4,044,259

Table 5.--continued.

Year	Head Quarters			Experiment Station	Total RRIM Expenditure
	Staff Emoluments	Other Recurrent Expenditure	Total		
1957	2,269,576	1,434,111	3,703,687	784,706	4,488,393
1958	2,892,015	1,868,357	4,760,372	793,888	5,554,260
1959	3,241,831	1,738,815	4,980,646	913,604	5,894,250
1960	3,596,803	2,283,871	5,880,674	1,044,085	6,924,759
1961	3,960,521	2,381,899	6,342,420	1,035,913	7,378,333
1962	4,460,221	2,545,464	7,005,685	1,175,673	8,181,358
1963	4,859,158	2,984,332	7,843,490	1,249,424	9,092,914
1964	5,770,414	2,860,111	8,630,525	1,398,053	10,028,578
1965	5,887,394	3,500,881	9,388,275	1,344,195	10,732,470
1966	7,009,648	3,878,941	10,888,589	1,448,798	12,337,387
1967	7,319,521	3,721,986	11,041,507	1,454,853	12,496,360
1968	7,783,041	3,539,354	11,322,395	1,478,768	12,801,163
1969	8,095,632	3,809,995	11,905,627	1,560,522	13,466,149
1970	8,475,236	4,448,703	12,923,939	1,552,850	14,476,789
1971	8,610,309	4,442,445	13,052,754	1,663,308	14,716,062
1972	8,952,138	5,288,202	14,240,340	2,084,619	16,324,959
1973	9,326,565	6,339,406	15,665,971	2,971,685	18,637,656

Source: Rubber Research Institute of Malaysia. Annual Statement of Accounts (1925-1973).

are in excess of a quarter million dollars a year (Table 6). In comparison to the RRIM budget, it is a relatively small amount, however.

Statement of the Problem

Although there is increasing empirical evidence that research plays a central role in promoting economic growth and that returns to investment in agricultural research have generally been two to three times higher than in alternative forms of agricultural investment, rubber differs in a number of ways from the crops that have so far been the subject of efforts to quantify the returns to research investment made on them.[42]

Aside from the fact that rubber is a perennial crop with an economic life span of about 30 years, in contrast to the annual crops such as hybrid corn, sorghum, rice, wheat, etc., which have been the main focus of earlier studies, a distinctive feature of rubber which sets it apart from these crops, is that a significant part of the industry is under foreign control, and in the organization of the two producing subsectors.

One manifestation of foreign control over such a large part of the industry is the repatriation of profits and earnings abroad by foreign owners and factors. It has been estimated, albeit crudely, that for the inter-War period between 45 and 55 percent of the rubber export earnings of the estate subsector was remitted abroad in the

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[42]Thomas M. Arndt and Vernon W. Ruttan, "Valuing the Productivity of Agricultural Research: Problems and Issues," in Resource Allocation and Productivity in National and International Agricultural Research, ed. Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977), p. 4.

Table 6.--Rubber Research Expenditures by Private Research Stations in Thousands of Current Malaysian Dollars.

Year	Prang Besar[a]			Rubber Growers Association	Other Stations[b]	Grand Total
	Breeding Program	Other Programs	Total			
1918				34	34	68
1919				34	34	68
1920				34	34	68
1921	15	5	20	34	34	88
1922	20	5	25	34	34	93
1923	20	5	25	34	34	93
1924	20	5	25	34	34	93
1925	20	5	25	34	34	93
1926	20	5	25	34	34	93
1927	30	10	40		20	60
1928	30	10	40		20	60
1929	30	10	40		20	60
1930	30	10	40		20	60
1931	30	10	40		20	60
1932	35	15	50		25	75
1933	35	15	50		25	75
1934	35	15	50		25	75
1935	35	15	50		25	75
1936	35	15	50		25	75
1937	45	15	60		30	90
1938	45	15	60		30	90
1939	45	15	60		30	90
1940	45	15	60		30	90
1941	45	15	60		30	90
1942-45	45	15	60		30	90
1946	45	15	60		30	90
1947	50	20	70		35	105
1948	50	20	70		35	105
1949	60	20	80		40	120

Table 6.--continued.

Year	Prang Besar[a]			Rubber Growers Association	Other Stations[b]	Grand Total
	Breeding Program	Other Programs	Total			
1950	60	20	80		40	120
1951	60	20	80		40	120
1952	65	25	90		45	135
1953	65	25	90		45	135
1954	65	25	90		45	135
1955	75	25	100		50	150
1956	75	25	100		50	150
1957	75	25	100		50	150
1958	90	30	120		60	180
1959	90	30	120		60	180
1960	100	30	130		65	195
1961	65	65	130		65	195
1962	70	70	140		70	210
1963	70	70	140		70	210
1964	75	75	150		75	225
1965	75	75	150		75	225
1966	85	85	170		85	255
1967	110	90	200		100	300
1968	90	70	160		80	240
1969	100	80	180		90	270
1970	100	80	180		90	270
1971	100	80	180		90	270
1972	90	70	160		80	240
1973	100	80	180		90	270

Sources: 1. Rubber Research Institute of Malaya Annual Report, 1928.
2. Prang Besar Research Station.

[a]Figures from 1921 to 1966 were estimated.

[b]Figures since 1927 were estimated.

form of repatriated profits, salaries, and wages.[43] As there was no income tax system at the time and the only form of taxes paid by the rubber industry was a token export tax, Malaysia's loss was largely the United Kingdom's gain.[44] Comparable estimates of smallholder contribution are not available, but on the basis of "qualitative information" Radhakrishnan concluded that the "contribution of smallholder rubber exports to gross national value added was about 50 percent higher than the estate subsector's contribution."[45]

It should, however, be emphasized that because of the higher yields per acre and the consequent higher value added per acre by foreign-owned estates, gross national value added per acre on these estates can exceed the gross national value added of locally-owned estates and smallholdings, after taking due account of the amount repatriated. This was especially evident during the post-War period. The contribution to value added by each mature acre of foreign-owned estates in 1964 was estimated to be some 67 percent higher than the comparable contribution by smallholdings.[46] This was possible because average yield per acre on foreign-owned estates was double that of smallholdings. The yield differential was enough to offset the higher

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[43]Radhakrishnan, "Role of Rubber in West Malaysian Economy, p. 118.

[44]D. M. Figart, The Plantation Rubber Industry in the Middle East (Washington, D.C.: Government Printing Office, 1925).

[45]Radhakrishnan, "Role of Rubber in West Malaysian Economy, p. 119.

[46]Ibid., p. 126.

labor costs, salaries, depreciation, and repatriated income on foreign-owned estates.

Another implication of the manifest differences between the two producing subsectors is that production on estates, which is characterized by high capital and labor costs, is likely to be price unresponsive. In fact as will be seen later in Chapter IV, the price elasticity of supply of estates is for all practical purposes zero. Production on smallholdings, on the other hand, is likely to be more price responsive although still relatively inelastic. Such fundamental differences between the producing subsectors, in terms of organization, inputs and ownership, warrant that estates and smallholdings be treated separately in any quantification effort of the benefits from rubber research received by the industry.

A second important difference between rubber and the other crops that have been analyzed is that 98 percent of Malaysian rubber production is exported. This necessarily means that the benefits generated in the form of lower prices and better quality product enjoyed by foreign consumers of Malaysian rubber cannot be captured by Malaysia. On the other hand, some consumer countries like the UK and the US are in the enviable position of being able to enjoy both the consumer and producer benefits of research undertaken by Malaysia.

The third difference between rubber and other crops mentioned is the officially-sponsored post-War replanting scheme or program which complemented and reinforced the work on the breeding and selection of high yielding rubber. The replanting program has been described as one of the most ambitious modernization programs ever undertaken in tropical agriculture.

In view of the unusual characteristics displayed by rubber the moot question is not only whether returns to rubber research per se are high. It is also whether the benefits received by producers in Malaysia, particularly the smallholding subsector, are sufficiently high as to justify the country's massive investment on rubber research. A related issue has to do with the divergence in research benefits between different factors of production. Another question concerns the extent of secondary benefits or linkages that the industry generates and that research contributes to.

Although not directly an issue, it may be important, in view of Malaysia's successful deployment of science and technology to transform rubber from a resource-based to a science-based product, to document in some detail the evolution of Malaysia's rubber research network and to consider whether it can serve as a model for other developing countries and for other primary agricultural commodities.

The Malaysian experience with rubber and rubber research may also serve as a good test of the applicability of the "induced development model" proposed by Hayami and Ruttan.[47] The main thrust of the model is that the capacity to generate an ecologically adapted and economically viable agricultural technology is indispensable for success in achieving growth and agricultural productivity. There are good grounds to believe that the Malaysian strategy of utilizing rubber research to induce economic development is consistent with the induced development model.

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[47]Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore and London: The Johns Hopkins Press, 1971), pp. 26-63.

Specific Research Objectives

The main purpose of the study is to contribute to the fund of empirical evidence on the use of agricultural research as a source of economic growth in developing countries. The specific research objectives are:

1. to document the evolution of the Malaysian rubber research network which enabled her to build and support a viable and productive industry;
2. to test the consistency of the Malaysian experience in rubber and rubber research with the "induced development model";
3. to estimate the returns to Malaysian society from investments in the rubber research program.
4. to evaluate the distribution of research benefits between the rubber producing subsectors and between different factors of production;
5. to attempt to assess the secondary benefits or linkages generated by the rubber industry.

At this juncture, it is perhaps appropriate to define the term "research." "Research," in a narrow sense, has been defined as "original investigation directed to the discovery of new scientific knowledge," and "development" as "technical activity concerned with non-routine problems encountered in translating research findings into products and processes."[48] Research is conducted to obtain new knowledge, whereas development is required to reduce the knowledge to

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[48] E. Mansfield, Industrial Research and Technological Innovation (New York: Norton, 1968), pp. 6-7.

practice. Much of the technology-producing activity in a college of agriculture, for example, fits the description of research while development would be associated with activities such as plant breeding and selection, and product testing.

In common usage, the word "research" is used as a generic term to include both activities described above. Unless otherwise specified, this will be the usage adhered to in this thesis.

Organization of the Thesis

Chapter II explores how Malaysian rubber research induced development in the nation. The validity of the induced development model is examined against the background of the historical evolution of rubber research.

Chapter III focuses on the diffusion of *Hevea* seeds/seedlings and the development of high yielding materials. The proximate date when Malaysia attained the capacity transfer phase in high yielding materials is also assessed.

Chapter IV sets out the theoretical framework for quantifying social returns from agricultural research in general. The procedure used to quantify returns from rubber research in Malaysia is then discussed.

Chapter V reports on the quantitative findings. The distribution of research benefits between consumers and producers, between the two different producing subsectors and between different factors of production is analyzed. The extent of secondary benefits produced by the industry is also examined.

Chapter VI summarizes the main results of the study and attempts to draw some policy implications. The need for additional work on the subject is also discussed.

CHAPTER II

RUBBER RESEARCH AND INDUCED DEVELOPMENT

It was suggested earlier that the Malaysian experience with rubber and rubber research makes it a good test case of the "induced development model," since research plays a key role in inducing development in the model. A country's ability to develop technology and institutions that are appropriate to its resource endowments is the central theme of the induced development model. To provide both historical perspective and insight into technical and institutional changes over time, the evolution of rubber research, with specific reference to Malaysia, is first detailed. A brief summary of the induced development model is next provided and its applicability to Malaysia is then tested in a general way.

Early Research

Research on rubber can probably be traced to the Indians in the jungles of Brazil who found that rubber would keep better if dried in the smoke of a wood fire.[1] But compared with the growth of rubber

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[1]Planters Bulletin, No. 32 (1957), p. 81. The smoke of a wood fire may contain minute quantities of sulphur, creosote, and carbon which, being deposited on the drying latex, give it color and a higher degree of hardness than ordinary air-dried latex. Apparently the reinforcing powers of carbon black, produced by the incomplete burning of natural gas, which was not discovered by S. C. Mote until 1904 was almost accidentally used from the earliest days.

cultivation, the progress of research, has been slow. Vulcanization, a most important discovery, which opened up many uses for rubber, was not known as a scientific process until well into the nineteenth century. During this early period, rubber research was virtually identified with research into the techniques of manufacturing. It was not until the basis of a manufacturing industry was laid and rubber began to be cultivated widely on a commercial scale that attention was turned towards production (biological and chemical) research.

The first person to bring a scientifically trained mind to bear on the everyday problems connected with growing the rubber tree and obtaining latex from it was H. N. Ridley, the acknowledged father of the Malaysian rubber industry.[2] When Ridley took up his appointment in 1888 as Director of the Botanic Gardens, Singapore, he found both government and planters totally indifferent to the possibilities of Hevea. Ridley immediately took an interest in the 1200 or more trees in the Gardens, which were the progeny of the original 22 Wickham seedlings, but it was not until about ten years later that anyone considered planting rubber on a commercial scale. He widened the distribution of the Hevea trees by planting in the forest reserves of Singapore and Malacca, in Peninsular Malaysia, and lost no time in commencing tapping experiments.

Hitherto all previous techniques of tapping were based on the Brazilian incision method, including that conducted by H. Trimen in Ceylon in 1884. The main difficulty of the incision method, which required cuts to be made into the tree by striking with an unguarded

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[2]Ibid.

instrument through the bark, was to gauge accurately the depth of the cut and prevent wounding, as otherwise the bark would be ruined for subsequent retapping. There was, moreover, no proper channel along which latex could flow into a collecting receptacle.

Ridley's discovery or invention of excision in 1889 overcame these problems. Excisions were made, either with mallet and chisel or a guarded knife which he designed, each cut being progressively widened at every tapping by removing or paring off a thin sliver of bark from the lower edge. The depth of bark available was shown by the initial excision, enabling greater precision in subsequent tapping and reducing the incidence of wounding. The all-important rate at which bark was used up could be controlled and since a new layer of smooth bark grew over the cuts in time, retapping was possible and therefore the economic life of the tree was substantially lengthened. A further significant result of the excision technique was the phenomenon which came to be called "wound response."

Wound response is inherent in and peculiar to _Hevea_.[3] The lactiferous tissue of _Hevea_ is composed of a number of vessels and by constant branching forms a complete and extensive network. The comparatively disconnected nature of this system possibly explains the poor initial yields of _Hevea_. On being reopened, fresh tubes are severed and an increased flow of latex results. The significance of wound response was that _Hevea_ could, in the long run, outyield other rubber species. This discovery effectively established _Hevea_ as the

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[3]J. Parkin, "Tapping and Wound Response." _India Rubber Journal_ 39 (1910):428.

most suitable plantation crop. The discovery of this phenomenon meant that trees could be tapped without at the same time destroying their yielding powers for the future. It has been acclaimed "as the most significant event since the introduction of rubber from tropical America and the greatest discovery after vulcanization."[4]

The decline of coffee cultivation in the country, following the depredations of disease, the increasing demand for and price of rubber on the world market were important factors leading to the planting of rubber on a commercial scale. But there can be little doubt that Ridley's discovery of excision tapping and persistent propaganda were essential contributions.[5]

Most observers of the industry agree that the first "plantation" development in the country was the planting of 40 acres of Hevea at Bukit Lintang, Malacca, by a Chinese planter, Tan Chay Yan, in 1896 or thereabouts. (Hitherto all rubber planting was experimental, largely undertaken by government officials and some coffee planters.)

The advent of commercial interest in rubber cultivation raised many problems. Planters were now anxious for further information and reassurance on many points such as tapping methods, latex preparation or processing, yields and susceptibility of the trees to diseases. All these had been anticipated by Ridley and his assistants, who had devised means of coagulating latex for shipment and studied conditions of tree growth and diseases.

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[4]P. K. Voon, Western Rubber Enterprise in Southeast Asia, 1876-1921 (Kuala Lumpur: University of Malaya Press, 1976), p. 23.

[5]P. R. Wycherley, "The Singapore Botanic Gardens and Rubber in Malaya," The Gardens Bulletin 17 (Singapore, 1959):180.

As a result of the research work described, planters taking up rubber growing in the late 1890s were able to benefit from the knowledge, albeit crude, accumulated on the theory and practice of rubber cultivation and production.

Despite Ridley's pioneer contributions to rubber research, the colonial authorities at the time seemed to have restricted his influence as much as possible. Wycherley has suggested that one of the reasons why the foundation of official rubber research in Malaysia was such a long drawn out process was the direct outcome of official efforts to ostracize Ridley.[6]

Although official research work was extended with the creation of the post of Superintendent of Experimental Plantations in 1900, research work as a whole at this stage was largely uncoordinated; each man pursuing his own line of enquiry which led to wasteful duplication of effort. Thus, the United Planters Association had urged the government as early as 1899 to set up an agricultural department to "aid all cultivators European and Native to give reliable information to those who might be induced to become cultivators."[7]

It was not until 1905 that the Department of Agriculture was established. Rubber research was now the responsibility of the Department but it was hamstrung by lack of money, staff, and equipment. Moreover, the new Department was responsible for research on all crops

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[6] P. R. Wycherley, "Natural Rubber and Malaysia." Draft contribution to the Rubber Golden Jubilee Number, 1975.

[7] J. M. Drabble, Rubber in Malaya, 1876-1922: The Genesis of the Industry (Kuala Lumpur: Oxford University Press, 1973).

although rubber was recognized to be the most important. It was hard pressed to keep pace with progress. The research staff had little time to visit estates and technical information, for the most part, was disseminated to planters through the Agricultural Bulletin, which began to be published regularly by Ridley from 1901.

The industry, particularly European planters, were increasingly critical of the services provided by the Department.[8] It was evident that the Department would not be in a position to provide the research and extension services expected of it by the industry.

The two major problems faced by the industry during this early period were disease control and preparation of rubber for the market. A chemist and an entomologist were among the first of the research staff to be recruited by the Department but they were officially attached to the Institute of Medical Research. A number of private organizations, therefore, began to employ scientific officers, principally plant pathologists or mycologists and chemists, on their staff. Lanadron Estate had already employed a plant pathologist on its staff in 1909. The principal private research scheme was that operated by the Rubber Growers Association (RGA). To look after the interests of its member estates, the RGA decided to appoint researchers in both Malaysia and Ceylon. The RGA implemented its cooperative research scheme, which was to be financed by participating companies and private estates, in 1909. In Malaysia, a research chemist, Sidney Morgan, was

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[8]The rubber planters wanted research and services specifically for them; they did not want to see the effort of the Department dissipated among other crops (see Wycherley, "Natural Rubber and Malaysia").

appointed in 1910 to work on the problems of preparing rubber for the market. Experiments were initially conducted at Bukit Rajah Estate. A permanent building was later acquired, 1912, at Pataling Estate just outside Kuala Lumpur. Another scientist, G. S. Whitby, investigated variation in yield at Kajang. The number of scientists employed by the RGA eventually grew to six and a branch laboratory was opened in Ipoh.[9] The work was conducted along commercial lines, quite independently of the Department of Agriculture's program. In London, the RGA retained a firm of consulting chemists to direct and evaluate the work in Malaysia and Ceylon. This appears to have been the first research financed by the industry but carried out in a consuming country to have the benefit of close contact with the users of the product.

Aside from the RGA, a number of other private research stations were set up in 1910. They included the stations of the Malay Peninsula Agricultural Association (MPAA), and the Societe Financiere des Caoutchoucs (SOCFIN), a Franco-Belgian company.

The need for reorganization and centralization in rubber research to reduce wasteful duplication of work, and the need for closer coordination of research programs was becoming increasingly evident. But although a proposal to merge official and private work under a central body was mooted by the RGA as early as 1917, it was not until 1925 that legislation was finally enacted to set up the RRIM. It may be of interest to note that the RRIM was set up despite the fact that a rubber restriction scheme, the so-called Stevenson Restriction Scheme, had been put in force in Malaysia and Ceylon in 1922.

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[9] Planters Bulletin, No. 32, p. 81.

Centralized Research

With the establishment of the RRIM, the research work on behalf of the rubber industry was transferred to it from the Department of Agriculture. At the same time, most of the non-official or private research stations in the country were closed down. The research station at Prang Besar Estate was probably the most important private station to continue work after the RRIM was established. The RGA laboratory at Pataling Estate which closed down on October 31, 1926, was taken over by the RRIM.

The first Director, G. Bryce, who had previously been engaged in rubber research in Ceylon took up his new duties on September 26, 1926. He was joined on November 1, 1926, by E. J. Eaton who had been the chief chemist in the Department of Agriculture, and by A. R. Sanderson and H. Sutcliffe, two pathologists who had been working on the selection of the Pilmoor clones for the RGA. Further staff joined in 1927 including three field officers to provide advice to estates and smallholdings, making a total of just over twenty senior staff and a budget of just under a quarter of a million dollars.

It was mentioned earlier that past scientific work on rubber was almost exclusively confined to two main lines of research, i.e., chemical investigations into the preparation and properties of the product, and pathological investigations into the diseases of the crop. Great importance was attached to disease work, perhaps owing to the impression made on the public by the disastrous effects of the coffee leaf disease in Ceylon. As a result of the interest in pathological problems, biological appointments during this period were generally given to mycologists. The mycologist, however, as his work progressed and as he accumulated experience found that he was frequently unable to advance further in his own investigations until the lack of information on basic physiological and soil problems were made good. In the absence of work in these branches he had to attempt the work himself or leave his own investigation incomplete. This resulted in progress being slow and in inadequate investigation in other branches since no one can hope to be a specialist in several branches of agricultural science.[10]

By the time the RRIM was about to be established, there was realization both among research workers and practical planters of the fundamental importance of crop improvement and soil management. In planting circles, interest in crop improvement and soil management had been awakened by the prospect of obtaining, through budgrafting from high yielding trees (more details of which will be provided in the next chapter), a greatly improved stand of trees from the cropping point of view, and by the marked results obtained on poor soils from the application of nitrogenous fertilizers. Another view gaining support among European planters was that work on seed selection should be undertaken to breed high yielding and disease-resistant trees.

In organizing the scientific work of the RRIM, it was considered essential that adequate provision be made for investigation into crop improvement and soil management as central functions of the RRIM.[11] The first four research divisions set up: botanical, soils,

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[10]Rubber Research Institute of Malaya, Annual Report (Kuala Lumpur, 1928).

[11]Ibid.

pathological, and chemical, reflected recognition of the central issues and views of the day.

The revenue of the RRIM was initially provided by a special export duty or cess of ten cents a picul (133 $\frac{1}{3}$ pounds) on all rubber produced in and exported from the country.[12] The cess was not levied during the duration of the Stevenson Restriction Scheme, which was in force in Malaysia and Ceylon from 1922-28. Instead its equivalent was contributed to the RRIM by the states concerned out of the general revenue accruing from the export duty on rubber (Table 7).

The Stevenson Restriction Scheme was followed not long after by the Great Depression, and its corollary, the International Rubber Regulation Agreement (IRRA), 1934. A novel feature of the Agreement was its provisions for the establishment of an International Rubber Research Board (now the International Rubber Research and Development Board) to undertake research towards increasing the consumption of rubber and publicity to stimulate new uses on rubber. Under the Agreement, the largest producers, British, Dutch, and French, were to establish national research and publicity units. Finance was to be provided by the imposition of a special cess of 1 penny per 100 pounds of rubber exported from the respective producing territories, plus a special levy from French Indo-China.

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[12]This had been agreed to earlier by a motion passed at the Federal Council Meeting held on November 25, 1924, to impose "a special export duty on rubber of 10 cents a pikul, in addition to any other duty, the proceeds of such special duty to be devoted to the support of the Institute, but . . . that such special duty should not be imposed and that the Institute should be supported out of the general revenue of the Federated Malay States as long as the present export duty under the Rubber Restriction Enactment, 1924 is in force."

Table 7.--Rubber Research Cess in Peninsular Malaysia.

Period	Rate
January 1925-January 1933	$50,000 per year from Johor, and 10 cents per picul on rubber exported from the Straits Settlements and other States.
February-December 1933	$50,000 per year from Johor, and 8 cents per picul on rubber exported from the Straits Settlements and other States.
January 1934-May 1934 (From June onwards the amount collected for the RRIM was included in the comprehensive cess of one cent per pound levied under the 1934 Rubber Regulation Legislation)	$50,000 per year from Johor, and 7 cents per picul on rubber exported from the Straits Settlements and other States.
January 1935-September 1936	7 cents per picul on rubber exported from the Straits Settlements and other States.
October 1936-1941	10 cents per picul on rubber exported from the Straits Settlements and other States.
September 1945-October 1946	Contribution by British Military Administration and Malayan Union Treasury.
November 1946-September 1949	0.25 cent per pound on rubber exported.
October 1949-May 1950	0.40 cent per pound on rubber exported.
June-December 1950	0.50 cent per pound on rubber exported.
January-December 1951	0.35 cent per pound on rubber exported.
January 1952-February 1953	0.40 cent per pound on rubber exported.

Table 7.--continued.

Period	Rate
March 1953-December 1958	0.50 cent per pound on rubber exported.
January 1959-December 1964	0.75 cent per pound on rubber exported.
January 1965-May 1967	0.875 cent per pound on rubber exported.
Commencing June 1967	1.00 cent per pound on rubber exported.

Sources: 1925-46 (October): Rubber Research Institute of Malaya, Annual Report (various issues).

1946-67: T. Y. Pee and Ani b. Arope, Rubber Owners Manual: Economics and Management in Production and Marketing (Kuala Lumpur: RRIM, 1976), Table 14.1, p. 189.

The three national units set up under the Agreement were:

1. The British Rubber Producers Research Association (BRPRA) now MRPRA, which took over the research activities of the RGA in London, and the British Rubber Publicity Association (BRPA) now MRB;
2. The Rubber-Stichting (Rubber Foundation); and
3. L'Institut Francais du Caoutchouc.

It was also agreed among the signatories that 20 percent of the cess money should be spent on publicity.

In Peninsular Malaysia, a comprehensive cess of 1 cent per pound was collected on all rubber exported under the Rubber Regulation Legislation of 1934. This revenue was used to finance the research activities of the RRIM as well as the BRPRA and BRPA.

The MRRDB Network: Development and Coordination

In 1936 the original rubber regulation enactment was repealed and replaced by a new Rubber Regulation Enactment (No. 37). This provided for the appointment of an official Controller of Rubber, an Advisory Committee and the setting up of a Malayan Rubber Fund, the financing of which was provided by a rubber cess.

The objectives to which the Fund might be devoted were:

a. the payment of the expenses connected with the administration of rubber regulation in Malaysia,
b. the payment of the relevant portion of the expenses of the International Rubber Regulation Committee, and
c. the payment of contributions to the RRIM, BRPRA, and BRPA.

Following this Enactment, the income from the rubber cess has ever since been administered by the Rubber Fund.

Although the RRIM was supposed to be receiving an income based on a cess of 10 cents per picul of rubber exported, problems inevitably arose under the Rubber Regulation. This was because the export of rubber released each year was variable; unless the export release for the year was more than two-thirds of the Malaysian basic quota, the assured income of the RRIM would not represent the full amount of the rubber cess.

It was unsatisfactory for the income of a research institution of this kind, the work and staffing of which must be planned on a settled basis, to be liable to variation within wide limits at the caprice of the world rubber market. Following the establishment of the Rubber Fund, the Controller of Rubber, as administrator of the Rubber Fund, agreed in 1938 to the stabilization of the income of the RRIM by basing the contribution from the Rubber Fund on the basis of the Malaysian basic quota instead of on annual exports. This ensured that a satisfactory and stable basis of income would be forthcoming to the RRIM for so long as the Rubber Regulation was in force.

The onslaught of the Second World War and the occupation of Malaysia by the Japanese from 1942-45 led to a virtual cessation of research activities both in the RRIM and the private research stations.[13] During this period most of the European senior staff were

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[13]During the Japanese Occupation, the RRIM was under Japanese management. Attention during this period was given primarily to methods of making gasoline by destructive distillation of crude rubber (Domei process) and, in view of Japan's shortage of shipping space, to methods of large scale storage of rubber for future use--see J. R.

either interned or killed. That any work could continue during these troubled years was due to the graduate assistants (mostly recruited from India) and the junior staff who remained at their posts.

Following the surrender of the Japanese in 1945, the task of restaffing and rehabilitating the RRIM began in earnest. The RRIM owed much to the prompt action of the then Director, H. J. Page, in convening a Board Meeting as soon as hostilities ceased in 1945, so that reconstruction could begin at once.[14]

Other changes wrought by the War included the development of a viable, large scale synthetic rubber industry, principally the handiwork of the Rubber Reserve Project in the U.S., and the dilapidated state of the rubber industry.

Another obstacle to research was the proclamation of an "Emergency" in the country in 1948 to combat a communist guerilla insurgency which was to last twelve years.

The principal attention of the RRIM was centered on its newly-developed rival, synthetic rubber. To ensure that the Institute was equipped to withstand the challenges of synthetic rubber and to counter the increasing cost of production on estates and smallholdings, a review of the direction and organization of work in the RRIM was deemed necessary. The corollary of this was the setting up of the

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Scott, "Research Institutions and Cooperative Research," in History of the Rubber Industry, ed. P. Schidrowitz and T. R. Dawson (Cambridge: Heffer and Sons, 1952), p. 190.

[14]Wycherley, "Natural Rubber and Malaysia," p. 28.

first five-year research program (1949-53) by the RRIM, BRPRA, and BRDB, units supported by the Rubber Fund.[15] Four lines of action were advocated:

1. to increase efficiency of production methods and so maintain for natural rubber a strong competitive position on a cost basis;
2. to better the standards of quality by improved methods of preparation and so increase the acceptability of natural rubber to manufacturers;
3. to improve current forms and develop new forms or derivatives of natural rubber capable of competing with the rival synthetic products; and
4. to strive for expansion of present uses of natural rubber and to extend its use to new fields.

The first two measures were to be the main responsibility of the RRIM. The RRIM would close ranks and work closely with the BRPRA and the BRDB on the other two.

The inadequacy of research funds was increasingly a problem, particularly after the completion of the first five-year program. This constraint was also noted by the 1954 Mission of Enquiry into the Rubber Industry in Malaya.[16]

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[15] Federation of Malaya, Legislative Council Paper, No. 40, 1949.

[16] The Mudie Mission recommended that the key to the future of the industry was through replanting. The replanting program required intensified research into many aspects of husbandry.

To plan for its long term development and expansion, the RRIM recommended in 1954 that the industry, through the RPC, should seek independent advice on the present and future form that research and technical services financed by the, then, Malayan Rubber Fund (MRF), should take.

An advisory committee, under the chairmanship of Professor Blackman from Cambridge University, was formed in 1956 to enquire into production, development, and consumption research in the rubber industry. After detailed investigations and discussions with the representatives of the industry and the Board and staff of the RRIM and that of the BRPRA and BRDB (which were subsequently renamed the Natural Rubber Producers Research Association and the Natural Rubber Bureau, respectively), the Blackman Report was released in 1957. It recommended the integration of the various research and development organizations funded by the MRF and the reorganization of the MRF itself. (It had become increasingly clear that the past practice of appointing a senior civil servant who lacked executive power as Controller of Rubber was obsolete and ineffective.) Following discussions with the Government a new legislation was enacted to consolidate research in natural rubber under the Malayan Rubber Fund Board (MRFB) which came into existence on January 15, 1959 (two years after the country attained independence). Additionally the Report advised the Malayan Government to increase the cess contribution to research from 0.5 to 0.75 cents per pound.

The Blackman Report also contained a number of recommendations on the work of the RRIM, including the following:

1. Expansion of the work of the Botanical Division with increased attention to improved methods of propagation, the production of high yielding seedling families and further developments of the work on yield stimulation; and
2. To strengthen the role of advisory services to the industry, the staff of the Smallholders Advisory Service (which was set up in 1937) should be expanded and an Estate Advisory Service set up. (Hitherto, advisory services to estates were performed by the various research divisions themselves.)

Almost all the recommendations of the Blackman Report were accepted and implemented in due course. A newly reconstituted Malayan Rubber Fund Board (MRFB) was soon established, comprising representatives from the industry and the government under a chairman who was ex officio the Controller of Rubber Research. To advise the Controller on all scientific matters, a Coordinating Advisory Committee (CAC) composed of eminent scientists from all over the world was set up in London (in place of the London Advisory Committee). The CAC works through two functional Steering Committees, one for research in the fields of rubber chemistry and technology, and the other for agricultural and biological research.[17]

The principles underlying the reorganization of the units financed by the MRFB were enunciated by the first Controller, Sir Geoffrey Clay, as follows:[18]

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[17] Planters Bulletin, No. 55 (1961), p. 109.

[18] Ibid., pp. 105-6.

1. Sole powers for the overall policy on research, the programs and policies of the various units, and the allocation of finances from the Malayan Rubber Fund to those units, should be concentrated in the Malayan Rubber Fund Board.
2. Directors of the units must be relieved of the routine administration and business affairs which inevitably arise in organizations as large as the RRIM and NRPRA. (These between them have budgets totalling more than ten-and-a-half million dollars for 1961.)
3. The Directors of Research at the NRPRA and the RRIM should be provided with high-level consultants. This is a continuation of the existing principle that the Directors of Research have access to the best scientific advice in the development of their research programs.
4. The non-technical day-to-day management of the individual units in the United Kingdom--the NRPRA, the RTD Ltd., and the NRB--must be well integrated.
5. For research on the crop up to the stage of shipment from Malaya, work carried out at the RRIM should be coordinated as far as possible with that of the research units maintained by some of the leading planting companies.
6. The programs of research and the development projects should be in proper balance and integrated where necessary.
7. The results of research are to be disseminated to the producers or the users for their adoption where they have been proved economic.

8. The complaints and advice of producers or users of the natural rubber product of Malaya must be obtained.

With the reorganization, the MRFB in effect became the controlling body under which the RRIM would operate. Further, the MRFB would, after consultation with the CAC, decide on the research program submitted by the Director of the RRIM. The Director of the RRIM, in turn, could turn to a panel of consultants to advise him on particular aspects of research before submitting his program of research to the MRFB through the CAC. Exactly the same procedure would be followed with the NRPRA and NRB.

This remained the structure of rubber research till 1972 when the Malaysian Parliament passed five new Bills to further streamline research and coordination, speed up the modernization of the smallholding subsector, modernize marketing methods, and encourage the growth of rubber manufacturing in the country. The changes which had direct bearing on rubber research in Malaysia included the following:

1. the formation of the Malaysian Rubber Exchange and Licensing Board (MRELB)--a body which superseded the Malaysian Rubber Exchange, the Malaysian Rubber Export Registration Board, and various state licensing boards--to streamline rubber marketing;
2. the establishment of the Rubber Industry Smallholders Development Authority (RISDA) to facilitate the dissemination of research innovations to smallholdings;
3. the MRFB was renamed the Malaysian Rubber Research and Development Board (MRRDB) and would now also be directly engaged in the planning and formulation of research strategies and policies; and

4. the enlargement of the activities of the RRIM to undertake

    a. rubber research for the whole of Malaysia
    b. end-use or consumer research
    c. adaptive research on strategic and selected smallholder problems through the formation of a new Smallholders Project Research Division to supersede the former Smallholders Advisory Service, but with the responsibility for implementation vested with RISDA.

To complement the work of the RRIM, the MRPRA (formerly NRPRA) and the MRB (formerly NRB) would continue to promote the interests of Malaysian rubber in the Western hemisphere, specifically, through seeking the development of new applications and improving the performance of rubber in existing applications. This should lead to further extending and consolidating its use. They would also ensure that consumers are fully aware of the many technical merits of natural rubber.

In retrospect, the organization and coordination of the MRRDB network (with production research centered in Malaysia, consumption or end-use research in Britain, and technical advisory offices or bureaus throughout the world) bears a strong family resemblance to that of the so-called international agricultural research institutes in the Philippines (IRRI), Mexico (CIMMYT), South America (CIAT), and West Africa (IITA).[19]

Coordination of the diverse rubber research activities by the different but complementary units of the MRRDB is vested with the

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[19]For more details on the international agricultural research system, see J. G. Crawford, "The Future of the International System: A View from Inside," in Resource Allocation and Productivity in National and International Agriculture, ed. Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977).

Controller and Chairman of the MRRDB who, as we have already seen, has a Consultative Advisory Committee (CAC) to advise him on research programs and priorities. In addition, there is a backup Panel of Consultants appointed from all over the world. The various international institutes come under the control of the Consultative Group of International Agricultural Research (CGIAR), a mixed group of sponsors and donors made up of international agencies, private foundations, and member countries. To assist in its work, CGIAR, like the MRRDB, has established a Technical Advisory Committee (TAC), whose functions are similar to those of the CAC. It appears, therefore, that the organization and coordination of the MRRDB research network has anticipated the international agricultural research system by at least a decade.

The Malaysian Experience and Induced Development

In the model of induced development proposed by Hayami and Ruttan, "technical and institutional change is treated as endogenous to the development process, rather than as an exogenous factor that operates independently of other development processes."[20] The basis for the statement is that "Technology can be developed to facilitate the substitution of relatively abundant (hence, cheap) factors for

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[20] "Technical change is defined as any change in production coefficients resulting from purposeful resource-using activity directed to the development of new knowledge embodied in designs, materials or organizations," see Hayami and Ruttan, Agricultural Development, p. 43. The term "institutional innovation (or change, or development) is used to refer to a change in the actual or potential performance of existing or new organizations (households, firms, bureaus); in the relationships between an organization and its environment; or in the behavioral rules or possibilities that govern the patterns of action and relationships in the organization's environment," see Vernon W. Ruttan, "Technical and Institutional Transfer in Agricultural Development," Research Policy 4 (1975):363.

relatively scarce (hence, expensive) factors in the economy."[21] The inducement process for technical and institutional changes results from what the authors term a "dialectical interaction" among farmers, scientists, and private entrepreneurs in response to relative factor scarcities and changes in the supply and demand of factors and products.

A major source of institutional change has been an effort by society to internalize the benefits of innovative activity to promote economic incentives for productivity increase. In some cases, institutional innovations have involved the reorganization of property rights, in order to internalize the higher income streams resulting from the innovation. Where internalization of the gains of innovative activity are difficult to achieve, institutional innovations involving public sector activity becomes essential. The socialization of much of agricultural research, particularly the research leading to advances in biological technology, represents an example of a public sector innovation designed to realize for society the potential gains from advances in agricultural technology. Institutional innovations, such as agricultural research stations, occur because it appears profitable for individuals or groups in society to undertake the costs.

Extension of the theory of induced innovation to explain the behavior of public research institutions represents an essential link in the construction of the theory of induced development. To do so the authors further hypothesize that the institutions that govern the use of technology or the "mode" of production can also be induced to change in response to technical and economic opportunities.

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[21] Hayami and Ruttan, Agricultural Development, p. 43.

The "theory of induced innovation" which the authors extend to the public sector may best be exemplified by a comparison of the U.S. and Japanese development experience. Historically, Japan has been a labor-plentiful, land-scarce economy, while the U.S. has been a land-plentiful, labor-scarce economy. Despite these very different resource endowments both countries modernized their agricultural sectors at a rapid rate, although in quite different ways. The U.S. concentrated on mechanization which increased labor productivity very substantially, but left land productivity practically constant. The Japanese, on the other hand, concentrated on biological innovations which, together with increased fertilizer use caused an increase in land productivity. Labor productivity, on the other hand, was almost untouched.

The technical innovations which made the alternative paths of productivity growth possible were the products of the public agricultural research stations in the respective countries. These public institutions represented the strategic institutional innovation on which the transition from a resource based to a science based agricultural system rests.[22]

In Malaysia, the resource endowment initially available was similar to the U.S., i.e., plentiful land. To pave the way for plantation or estate development, capital and labor constraints were overcome by importation of capital and skilled personnel primarily from the U.K., and unskilled labor from South India, South China, and Java. If these

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[22]Agricultural research stations exemplify a demand induced institutional innovation which in turn became an efficient supplier of technical innovation. For an excellent account of how this was brought about, see Ruttan, "Technical and Institutional Transfer."

imported factors were added to the country's land resource, the augmented resource endowment available to Malaysia would no longer be as extreme as that in the U.S. and Japan.

The feasibility of importing labor, enslaved, indentured or otherwise, led to the establishment of plantations or estates whose motive force was based on human power. Apart from Malaysia, the plantation system of agricultural resource organization was developed in the U.S. South, the Caribbean, Ceylon, Indonesia, and the Philippines.[23]

Although the system of operation on an estate is more extensive than on a smallholding (which, according to Beckford, is in any case largely created in the image of the estate and reflect its behavior) the plantation system is basically labor intensive.

The inducement mechanism came into play shortly after 1910 when rubber prices fell. To countervail falling rubber prices, estates resorted to drastic cost-cutting measures to streamline their operations. This took a number of technical and institutional forms. With the sharp fall in product prices which made the primary factors, land and labor, relatively expensive, estates instituted measures to reduce unit cost of production by using less of the relatively more expensive factors. The number of expensive European supervisory staff was reduced by substituting cheaper Asian conductors. In 1932 only one European was normally employed on an estate of from 1,200 to 1,600

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[23]Beckford, "The Economics of Agricultural Resource Use and Development in Plantation Economies," pp. 118-21.

acres, whereas in 1928-29 there were two and before World War I four.[24] This was coupled with major reductions in salaries and wages, directors' fees, and agency house commissions. The total effect of these economies was striking. It was estimated that by 1932, the costs of the highest cost producing companies registered in Malaysia had fallen to five-eights of those of the lowest cost producers in 1929.[25]

The economies had very harsh effects on estate workers. Although the reduction in their wages was, at this time, mitigated by the sharp fall in the cost of living, their employment was drastically reduced. The number of workers on the estates fell from 258,000 in 1929 to 145,000 in 1932.[26] Many thousands of workers and their dependents were repatriated to India--an example of the export of unemployment during the World Depression.[27] (Appendix A, Table 3 shows the estate labor force, by race, from 1933.)

Coincident with measures to reduce unit costs, estates exerted pressure on the government to impose restrictions in rubber output by the industry to raise product prices. The implementation of two pre-War rubber restriction schemes, as already discussed, was a measure of the political clout wielded by the estate subsector.

These were, however, short term expedients. In the long run, the most important avenue for reducing unit costs was through the

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[24]Bauer, The Rubber Industry, p. 254.

[25]Knorr, World Rubber and Its Regulation, p. 104.

[26]Bauer, The Rubber Industry, p. 254.

[27]Allen and Donnithorne, Western Enterprise in Indonesia and Malaya, p. 124.

introduction of high yielding materials--the product of land-saving biological research. In Malaysia, as in Indonesia, work on breeding and selection of high yielding materials was pioneered by research stations set up by the estate subsector.[28]

As mentioned earlier, the estate subsector and European planters, in particular, were the prime moving force behind the establishment of governmental rubber research, first, through the setting up of the Department of Agriculture and, later, the RRIM. Moreover, much of the early research activities at the RRIM was geared to suit the conditions of estates. A good illustration of this may be seen in the use of the common tapping system on estates, S/2.d/2, in programs of selection. Further, "dialectical interaction" between research administrators and staff was, evidently, mainly with the estate subsector, thus, prompting Bauer to refer to the RRIM as an Estate Rubber Research Institute.[29]

The post-War replanting program can be viewed as another institutional response; in this case to the challenge posed by synthetic rubber and the need to put the industry on a more competitive footing. The idea of a replanting cess to rehabilitate the industry had apparently been conceived by the industry.

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[28]In contrast to the attention on biological research, "Malayan-American Plantations Ltd. (a subsidiary of the United States Rubber Company) led the way in research into the mechanization of estates," Ibid., p. 127. This may have been influenced by American successes in the mechanization of agriculture in a land plentiful environment.

[29]P. T. Bauer, Report on a Visit to the Rubber Growing Smallholdings of Malaya, July-September 1946, Colonial Research Publications No. 1 (London: H.M.S.O., 1948), p. 42.

An additional institutional response was the passage of five new Bills by the Malaysian Parliament in 1972; in this case responding to the urgent need to modernize the smallholding rubber subsector. These actions led to the creation of the Rubber Industry Smallholders Development Authority (RISDA), and the Smallholders Project Research Division at the RRIM.

The historical evidence culled from the Malaysian experience with rubber and rubber research appears to be generally consistent with the induced development model. But it should be noted that since many of the technical and institutional changes were the direct outcome of pressures brought to bear by the estates, it can be expected that they would be the main beneficiaries of changes resulting therefrom. Again, since rubber is an export crop, some of the research benefits are likely to go to consumers abroad.

In a plantation economy, foreign ownership of estates limits development in two additional ways.[30] Firstly, there is the leakage of income in the form of dividends which reduces the investment capacity of the economy. Secondly, when reinvestment out of the surplus occurs, there is no assurance that the economy in which the surplus was produced will benefit. This follows from the fact that agency houses are multi-national corporations. Surpluses produced in one country can be reinvested in any other country where the firm has investments or at homebase in the metropolitan country. This suggests that the linkage effects or secondary benefits generated by the estate subsector are likely to be relatively small.

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[30]Beckford, "Economics of Agricultural Resource Use and Development Plantation Economics," p. 133.

In treating technical and institutional change as endogenous to the development process, the authors were careful to emphasize that this did not imply that agricultural development can necessarily be left to an "invisible hand" to direct either technical or institutional change along an "efficient" path determined by "original" resource endowments.[31] They further emphasize that "the policies which a country adopts with respect to the allocation of resources to technical and institutional innovation must be consistent with national physical and human resource endowments if they are to lead to an efficient growth path."[32] The most critical factor in the agricultural process, then, is how to organize and manage the development and allocation of scientific and technical resources. This is particularly critical in the case of developing countries. They argue that deficiencies faced by developing countries in a number of key areas, including technical competence of research personnel, inadequate financial, logistical, and administrative support, and lack of a modern marketing system, have impeded the creation, or where they exist, the optimum usage of research facilities.[33]

Having reviewed in some detail the historical evolution of rubber research, Malaysia appears to be an exception to the general lack of research activities in agriculture in developing countries.

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[31]Vernon W. Ruttan and Yujior Hayami, "Strategies for Agricultural Development," Food Research Institute Studies in Agricultural Economics, Trade and Development 11 (1972):143.

[32]Ibid.

[33]Ibid.

However that may be, it is clear that over the long run, the use of resources for rubber research in Malaysia must be justified in terms of the economic value of the research output or new knowledge that is produced. The sufficient condition for a high pay-off to research is apparently dependent on whether research capacity, in this case the diffusion and development of high yielding materials, has reached the critical "capacity transfer phase." This is important as "reliance on diffusion processes based primarily on material and design transfer can, in the absence of investment necessary to reach the capacity transfer level, severely bias the direction of technical change."[34] Hence, before considering whether the Malaysian experience in rubber research, which in historical perspective seems consistent with the induced development model, has resulted in a high pay-off, we consider next the diffusion and development (breeding and selection) of high yielding materials, and when the capacity transfer phase was reached in Malaysia. This can have obvious impacts on the rate of returns to rubber research.

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[34]Ruttan, "Technical and Institutional Transfer," p. 358.

CHAPTER III

DIFFUSION AND DEVELOPMENT OF HIGH YIELDING MATERIALS

This chapter will detail the diffusion of *Hevea* and the role played by Ceylon and British Malaya (Singapore and Peninsular Malaysia) in the diffusion process, before turning to the development of high yielding materials. We then attempt to fit the diffusion and development of high yielding materials in Malaysia into the three phases of technology transfer (material, design, and capacity) first outlined by Hayami and Ruttan.[1] The approximate date when Malaysia attained the capacity level can then be determined. The phase of technology transfer reached, as pointed out earlier, can have important effects on the rate of return from investment on rubber research in Malaysia. The success of plant breeding and selection has provided the potential for a four-fold increase in yield of the new generation of bred clones over the unselected materials in the forty year period from the 1920s to 1960s. This, however, reflects potential yield. The effective commercial yields on estates and smallholdings are then discussed.

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[1]Hayami and Ruttan, *Agricultural Development*, p. 175.

Diffusion of Rubber Seedlings/Seeds

The diffusion or transfer of agricultural technology is not a new phenomenon. Since prehistoric times the international and intercontinental diffusion of cultivated plants, domestic animals, hand implements and cultural practices were a major source of increased productivity. Just as the transfer of crops from the New World had a dramatic impact on European agriculture, the diffusion of crop varieties by colonial powers to their colonies provided the technological bases for staple export industries. Natural rubber, *Hevea brasiliensis*, is an excellent example of technology transfer--from the upper reaches of the Rio Tapajos in the Amazon basin of Brazil to the foothills of South and Southeast Asia, by way of the germination beds in the Royal Botanic Gardens at Kew, England.

The story of how *Hevea* seeds were collected and dispatched from the Amazon basin and the colorful cast of characters involved have already been described in some detail. What needs to be recounted here is the distribution of the seedlings mostly in Wardian cases (miniature greenhouses now popularly known as terrariums) from Kew and the role of Ceylon and Malaya as regional seed suppliers.

International Diffusion[2]

The diffusion of *Hevea* seedlings occurred as several successive "waves" from Kew serving as the epicenter. The first wave reached the botanic gardens of India, Ceylon, and Malaya, which in turn

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[2]This section and the one following draw heavily from P. K. Voon, *Western Rubber Enterprise in Southeast Asia, 1876-1921* (Kuala Lumpur: University of Malaya Press, 1976), pp. 4-13.

disseminated seeds to botanic gardens and experiment stations in the region. The final phase of diffusion was performed by local gardens in supplying seeds and plants to prospective planters.

The year 1873 marked the arrival of Hevea brasiliensis to the East when six plants raised at Kew from the Farris collection were dispatched to the Botanic Gardens at Calcutta, India. Calcutta was probably chosen because it was the major Indian botanic garden, as well as the fact that the plants were taken from Kew by the Superintendent of the Calcutta Gardens himself. From Calcutta, cuttings were subsequently sent to Sikkim, displaying the general ignorance of the climatic requirements of Hevea at the time. These plants, together with a later consignment sent to Calcutta in 1875, failed to survive and Calcutta ceased to serve as a depot for the dissemination of Hevea in India. A proposal to use Tenasserim in Burma (which was then part of British India) was abandoned. Instead, Ceylon which possessed a sufficiently well equipped botanic garden at Henaratgoda was selected to serve as a depot for the propagation and distribution of Hevea plants to India and Southeast Asia.

The first consignment of 1919 Hevea seedlings reached Ceylon from Kew in August 1876. Another 50 to 100 seedlings reached Singapore two days later but delays in freight payment by the India Office resulted in a serious loss--none of the seedlings apparently survived. In the same year, a small number of plants was sent to Buitenzorg, Java; 50 to Burma and 100 to Saharumpore, India. The following year, 1877, four dispatches were made from Kew, consisting of 22 plants to Singapore, 100 to Ceylon, 50 to Calcutta, and 4 to Buitenzorg.

Ceylon was the major recipient of the total of more than 2,300 seedlings sent to the East, although some of the seedlings were later redirected to other territories. Singapore, on the other hand, received less than 122 plants, of which only the second consignment of 22 plants survived. As mentioned earlier, 9 seedlings were later taken to Kuala Kangsar, Peninsular Malaysia, in 1877 by Henry Murton, Superintendent of the Singapore Botanic Gardens.

From this account it is clear that it was British initiative which led to the establishment of the rubber industry in South and Southeast Asia. It also explains subsequent British domination of the industry.

Regional Diffusion

By the early 1880s, a number of trees planted in the botanic gardens in Ceylon and Malaya had begun to flower. But it was Ceylon, which possessed 457 mature *Hevea* trees at Henaratgoda in 1887, that became the main regional seed supplier. By 1897, several estates in Ceylon began to meet mounting demand for *Hevea* seeds by selling seeds.

The role of Malaya in the regional diffusion of *Hevea* planting materials came later. It was centered at the Singapore Botanic Gardens, and supplemented by smaller experimental gardens in Taiping, Kuala Kangsar, and Penang, as well as some private estates.[3] Singapore became an important regional supplier of seeds in the 1890s, mainly to Peninsular Malaysia. By the mid-1890s, however, increasing amounts were shipped to such distant areas as Mexico, Hawaii, Jamaica,

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[3]At the time control over the various Gardens in what is now Peninsular Malaysia was vested with the Singapore Botanic Gardens.

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Australia, and Nigeria, turning Singapore into an international supplier of Hevea planting materials.

In Peninsular Malaysia, seeds for local distribution came from trees planted at Kuala Kangsar, Taiping, and Penang. As in Ceylon, a number of private planters who had planted rubber in the early 1890s were able to offer seeds for sale locally and, later, abroad, especially Java and Sumatra.

The rubber industry in what was then the Dutch East Indies was largely based on seeds imported from Singapore and Peninsular Malaysia. A significant contribution was the acquisition of 35 seeds by the Dutch Consul in Penang, and sent by him to Buitenzorg in 1892. These seeds probably came from the trees planted at Kuala Kangsar from the original 22 Wickham seedlings. The trees from the imported seeds were later to become the parent stock from which two important Indonesian clones were derived in the 1890s. The two mother trees selected were Cultuurtuin (Ct) 9 and 10.

Seeds from Buitenzorg were later obtained by a French mission from Indo-China in 1897, and these and later importations from Singapore formed the basis for the rubber industry there.

In neighboring Thailand (then Siam), rubber was introduced from Peninsular Malaysia in 1901 by the Governor of the province of Trang.

Thus, from the very beginning, Singapore and Peninsular Malaysia assumed a leading role in the regional diffusion of Hevea planting materials. This role was later consolidated by Peninsular Malaysia's success in rubber research. From a leader in the diffusion of planting materials it was soon to become the leading regional and international diffuser of new knowledge and technology in Hevea.

Development of High Yielding Materials

Initially, all rubber planted was from "unselected seeds" obtained from any available source.[4] The degree of selection practiced was limited to the collection of seeds from areas of healthy, well grown trees which by the standards of the time were giving a high yield of latex. The main disadvantage of using unselected seeds is the wide variability in yield. Moreover, the yield of unselected seedlings would not in general exceed 500 pounds per acre per year.

Early Attempts at Yield Improvement

The problem of yield improvement is primarily economic and only secondarily scientific. There is little doubt that, from the earliest days of agriculture, crop improvement by some elementary form of seed selection was practiced in the case of staple crops. According to Simmonds this has been going on for eight or nine thousand years.[5] The guiding principle was invariably that of an increased return at harvest or the maintenance of some special quality of the product.

It was not until the beginning of the twentieth century that science began to take part in this work, as the principles of breeding and selection, i.e., breeding on a genetical basis gradually became known. The main thrust of breeders and selectionists has been to increase yield, and the best plant has become defined as that which produces the greatest return.

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[4]A. T. Edgar, Manual of Rubber Planting (Malaya) 1973 (Kuala Lumpur: Incorporated Society of Planters, 1947), p. 73.

[5]N. W. Simmonds, "Genetical Bases of Plant Breeding," Journal Rubber Research Institute of Malaya 21 (1969):1.

The fact that plant improvement is not a simple process makes the assistance of the selectionist and plant breeder essential. Unfortunately, however, in spite of the great advances already made in the improvement of other crops the knowledge thereby accumulated is only of restricted value to the improvement of the rubber trees.[6] In the case of rubber, the conception of yield is a special one, for the product, latex, differs fundamentally from the crop of other plants. Latex is produced as a wound response by the tree during tapping. Furthermore, the planter is concerned almost exclusively with the quantity of latex and the question of quality hardly arises.[7]

Neverthless, there are distinct prospects of yield improvement by following the well-established methods employed by the selectionist and plant breeder with other crops. These methods fall into three classes:

1. seed selection,
2. vegetable selection or the multiplication in clones of the best types of a variable population, and
3. generative selection or breeding.

Seed Selection from High Yielding Trees

It was early observed in Java and Malaysia that when a Hevea population was raised on an estate by normal planting methods from

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[6] F. Summers, The Improvement of Yield in Hevea Brasiliensis (Shanghai: Kelly and Walsh, 1930), p. 3.

[7] The presence of non-rubber substances in the latex can affect the property of the product and fundamental study of latex is an important subject of research by the Fundamental Physics and Chemistry Division.

ordinary or unselected seedlings, the individual trees would be found to vary widely in productive capacity when they come into tapping. Moreover, the greater number would be found to give yields less than the average for the whole field, while an undue proportion of the crop would come from a relatively small number of high yielding trees. As an illustration of the variability, Whitby who started studies in 1913 was able to report that in an early population of over 1000 ordinary seedlings in Malaysia, 9.8 percent of the highest yielding seedlings produced 28 percent of the total crop.[8]

A simple way of ennoblement that has been practiced since man became an agriculturist is mass selection. In short the progenies of the best individual are used for the next planting. Before the advent of budding this method was used by rubber planters who wished to improve their seedlings. When budding became a practical proposition it was possible to fix the desirable characteristics of any one seedling tree in a clone.

The first organized attempt at yield improvement through mass selection was by a Dutch scientist, Cramer, working in Indonesia in 1910.[9] Cramer carried out his first variation analyses on 33 seedlings from Wickham trees imported from Penang, Malaysia, and planted in Buitenzorg (now Bogor), Java, in 1883. This resulted in the selection of a number of high yielding trees from which the first Indonesian clones were derived.

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[8] G. S. Whitby, "Variation in Hevea Brasiliensis," Annals of Botany 28 (1919).

[9] M. J. Djikman, Hevea: Thirty Years of Research in the Far East (Florida: University of Miami Press, 1951), p. 12.

With the knowledge obtained from his yield analyses on the Wickham seedlings, Cramer correctly pointed out that no one could know anything about the quality of the seed obtained from such sources. From his work in the Buitenzorg rubber plots, he realized the potential of using the genotypically heterogeneous material for breeding. He had already selected outstanding yielders from the 33 Wickham trees but since the technique of vegetative propagation was still in the experimental stage, no practical results were yet possible. In the interim, he tried his utmost to interest planters in the most elementary phase of seed collection. He led the way by picking the naturally pollinated seed of his select Wickham trees and urged the planters to do the same with the high yielders in their own groves. Recognizing the possibility of cross-pollinating by adjoining inferior yielders, he reasoned that the chances of obtaining better yielding plantings from such mother-tree seed would be far greater than from seed picked at random. Such seed would, therefore, be preferable to seed from entirely uncontrolled pollinations from abroad or grown locally. The results obtained with mother-tree seed collected with different degrees of precision are shown in Table 8.

Sumatra became the earliest commercial source of supply of this primitively selected seed, the prototype of the present day high yielding materials. A number of progressive plantations, of which the most prominent were Tandjong Merah, Marihat, and Tjinta Radja, specialized in this field and from 1916 (just before the establishment

Table 8.--Yield of Unselected and Selected Seeds on the East Coast of Sumatra.

Material	Year of Planting	Yield (lb/acre)
Unselected seed	before 1917	446
Mother tree seedlings	1917-18	575
Seedlings grown from mother tree seeds	1919-21	634

Source: F. P. Ferwerda, "Outlines of Perennial Crop Breeding," Miscellaneous Paper No. 4, Landbouwhogeschool Waginen, 1969.

of the AVROS General Experiment Station the same year) they supplied large quantities of this mother-tree seed.[10]

The commercial benefit of plantations grown with mother-tree seed was clearly demonstrated when, with the imposition of the 1934 International Rubber Restriction Scheme, Indonesia could show statistically that yields from these mother-tree seedling plantings were 40-70 percent higher than unselected seedlings.[11] The yields of the progenies were found to be 20-40 percent higher than unselected seedlings. That they were not as superior as the original selected mother-trees may be attributed to the cross fertilization of seeds by adjoining inferior yielders.

Later experiments have shown that if natural pollination is prevented and artificial or hand pollination (developed by Heusser in

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[10]The AVROS was one of a number of producer cooperative research organizations supported by European estate interests and the government in Indonesia.

[11]Djikman, Hevea, p. 13.

Sumatra in 1920) between selected high yielding parents is carried out, families of seedlings can be obtained which give very high yields.

The perfection of the budgrafting technique in the meantime led to the virtual cessation of efforts to improve yield through the breeding of seedling families of proved value.

Vegetative Selection

A short time after Cramer selected his high yielding trees from the second generation Wickham collection, van Helten, who was then Superintendent of the Economic Gardens, Buitenzorg, started experiments to propagate Hevea trees vegetatively. He reasoned that if Hevea could be multiplied vegetatively, and these propagations should prove to be identical to the high yielding mother-tree from which they were derived, commercial plantings could be established with a uniformly high production. He, therefore, proceeded to investigate the budding of Hevea from 1910. It was not until 1916 that van Helten, in collaboration with two Dutch planters, Bodde and Tas, succeeded in finding a method that was commercially feasible.[12]

With budgrafting, the sexual part of the plants play no part in the multiplication process. The buddings produced are identical genetically with the parent tree from which they were made. The trees obtained from this process are known as clones or cultivars.[13]

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[12]Ibid., p. 14.

[13]Since Hevea clones possess definite genetical characteristics and are reproducible vegetatively, they are cultivars, see P. R. Wycherley, The Cultivation and Improvement of the Plantation Rubber Crop, Rubber Research Institute of Malaya, Archive Document No. 29 (Kuala Lumpur, June 1964), p. 33.

The perfection of the budgrafting technique enabled full advantage to be taken of using identified high yielding materials in vegetative multiplication. These began at the AVROS in Medan, Sumatra. In 1918, after years of careful recording, and the building up of a collection of high yielding mother-trees, Heusser made from them a number of clones.

The results of this period are still with the industry. In Malaysia, they are represented by clones such as Tjir 1 (originally imported from Indonesia in the 1920s), Gl 1 and PB 86; in Indonesia by LCB 1320 and 510, and GT 1.

The yield of the primary clones was two to three times that of the unselected seedlings, but by the mid-1930s breeders had realized most of the progress possible from the old seedling materials through mass selection. Further progress would have to depend on intercrossing or breeding of the primary clones to create improved populations for subsequent selection. Consequently, systematic breeding programs using hand pollination techniques developed in 1920 by Heusser were started. By this means, the best clones available are crossed or individual crosses made to combine the high yield of one parent with the vigor or disease resistance of another, and legitimate progenies produced.

This new development in rubber breeding by the Dutch in Indonesia is easy to understand. Striking results had already been obtained by Dutch workers in the improvement of coffee, tea, sugar, and cinchona by methods of selection, breeding, and grafting. The advances made in these crops must have greatly stimulated and encouraged both research workers and planters to attempt to apply similar methods to Hevea.

In Malaysia, Whitby, Sanderson, and Sutcliffe from the RGA and Major Gough, founder of Prang Besar Estate, laid the foundations for Hevea improvement. (Preliminary budding experiments were instituted by the Department of Agriculture early in 1919 and, after interruption, were resumed in August 1920).[14] Whitby had made a systematic study of the variability of Hevea in 1918. Sanderson and Sutcliffe performed a similar set of experiments in Pataling Estate in 1923 and confirmed Whitby's findings that unselected materials were highly variable in their yields. They disbudded 21 trees from the highest yielding group and planted them in Pilmoor Estate in 1924. About the same time, Major Gough selected and disbudded 618 clones from a population of about one million seedlings in Kajang district, Selangor. These and other selections formed the primary clones. The most widely used of these include Pil A44, Pil B84, Pil B16, PB 23, PB 25, PB 86, and PB 186.

Systematic Breeding and Selection

Systematic Hevea breeding can be characterized as one in which clonal selection and generative breeding alternate in regular succession.[15] Seedling progenies from mass selection provide the initial material from which the next generation of clones is developed. Mother trees selected from the highly variable basic populations give rise to

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[14] Summers, The Improvement of Yield in Hevea Brasiliensis, p. 10.

[15] F. P. Ferwerda, "Rubber," in Outline of Perennial Crop Breeding in the Tropics, Miscellaneous Paper No. 4 (Land bouwhogeschool Wageningen, 1969), p. 439.

an elementary group known as primary clones. The primary clones which provided the first clonal materials for commercial plantings are also used as parents for controlled hand pollinated crosses to produce improved seedling materials.[16] These improved seedling families can either be used for large scale planting or further cloned. Elite secondary clones produced from the improved seedling families are selected and used for intercrossing to repeat the whole procedure, which can be continued almost indefinitely. Each full breeding cycle takes about 15 years from hand pollination or 30 years from hand pollination to recommendation for large scale planting (see Figure 2).

The procedures involved are perhaps best illustrated by detailing the stages of the RRIM breeding and selection program, as outlined below:[17]

I. The legitimate seedlings (when both parents are known) produced in the RRIM annual hand pollination programs are screened in the nursury together with "polycross" material.

II. The best seedlings from the nursery are cloned and tested in the Small Scale Clones Trail in the RRIM Experiment Station. About 300 to 400 clones are tested annually in the field.

III. The best clones from the Small Scale Clones Trial and selections from commercial research stations are tested in

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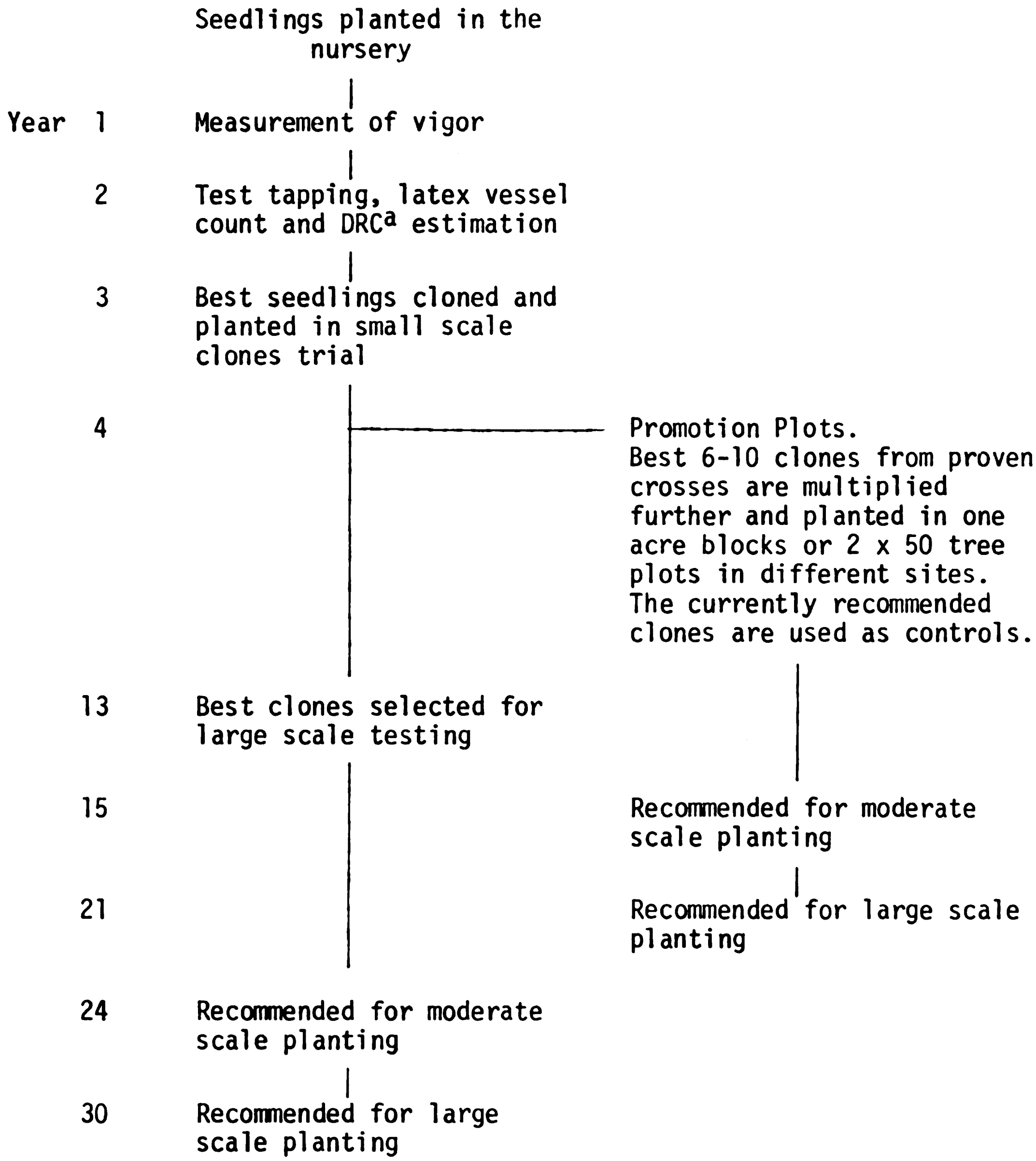
[16]L. E. Morris of the RRIM made the first series of hand pollination in Malaysia in 1927. R. J. Chittenden of Prang Besar also began to apply this method in 1928 (see Planters Bulletin, No. 23, March 1956).

[17]Five Year Research Program of the Plant Science Division, 1976-1980, Rubber Research Institute of Malaysia (Kuala Lumpur, 1975).



[a]Dry rubber content.

Source: S. Subramaniam, "Recent Trends in the Breeding of Hevea," Indian Journal of Genetics 34A (1974):138.

Figure 2. Period of Testing for Clones--Flow Chart.

the RRIM Station and cooperating estates. About 10 to 16 new clones are tested in these trials which are established every three to four years.

IV. The best clones are recommended to the industry in stages based on the information available on their performance. The recommendations known as the RRIM Planting Recommendations (see Table 4) are made every two years. Only clones which have been sufficiently tested and recommended for large scale planting to estates are recommended to the smallholding subsector.

In addition to the clones produced locally by the RRIM and private stations, the Institute also obtains clones produced by other research organizations abroad and tests them for local adaptation. The promising ones may be recommended to the industry after stringent testing.

The bulk of the breeding work at the RRIM has been focused on the breeding of trees with high yield and good vigor. This work began in 1928 and, excepting for two brief periods of interruption caused by the Great Depression, when the first plant breeder, L. E. Morris was retrenched while on home leave and the breeding program suspended from 1931-37, and the Japanese Occupation from 1942-46, has continued ever since.[18] Much of the earlier work between 1928 to 1963 was summarized by Ross and conveniently divided into four phases:[19]

Phase	Duration	Clonal Series
I	1928-31	RRIM 500
II	1937-41	RRIM 600
III	1947-58	RRIM 700
IV	1959-65	RRIM 800

The first phase began when Morris, between 1928 and 1931, made seven series of crosses, using as parents buddings originally established on Pilmoor Estate in 1924, and some other clones made from estate selected mother trees.[20] The legitimate seedlings so obtained were planted at the RRIM Experiment Station from 1929 to 1932, and brought into tapping in 1935 and 1936. Wide differences in yield were found among the individual members of each family, but the range of variation was less than that of illegitimate clonal seed and unselected seedlings. From the seedling crosses, 984 new clones were made and later tested in small scale trials. From the test, 30 clones were selected for further trials (large scale) and given numbers in the RRIM 500 series.

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[18]The adverse consequences of this incident to the industry and country must have been considerable since breeding and selection subsequently proved to be the greatest single contribution to the viability of the industry (see Wycherley, "Natural Rubber and Malaysia," p. 28).

[19]J. M. Ross, "Summary of Breeding Carried Out at the RRIM during the Period of 1928-1963," Rubber Research Institute of Malaya, Archive Document No. 28 (Kuala Lumpur, 1964).

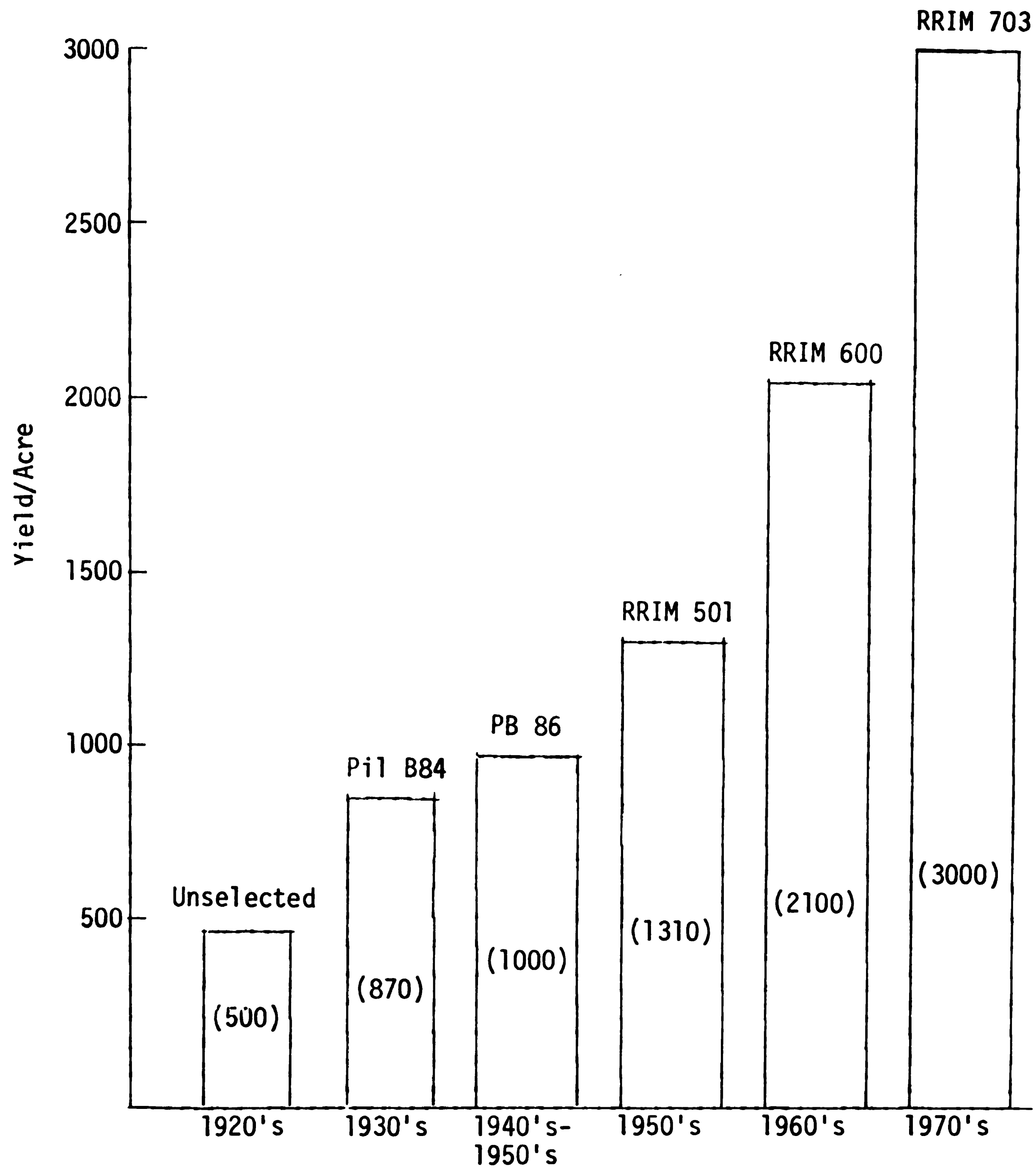
[20]A. T. Edgar, Manual of Rubber Planting (Malaya), 1958 (Kuala Lumpur: Incorporated Society of Planters, 1960), p. 34.

The second stage of the RRIM breeding program commenced in 1937, using the most promising clones developed locally and from Java and Sumatra. (From the mixed parentage of clones used in breeding, it is clear that the clones in commercial production are mostly joint products of research organizations both locally and from abroad). Of 2,186 new clones made between 1937 and 1941, 39 were selected. These constitute the RRIM 600 series.

Breeding work resumed in 1947 after the War. The selected clones made between 1947 to 1958 make up the RRIM 700 series. Additionally, there have been two other phases: 1959 to 1965 and 1966 to 1973.

The mean yields of the more popular clones from three of the first four RRIM clonal series are depicted in Figure 3. There has been a four fold increase in yield of the new generation of bred clones over the unselected seedling material over a period of forty years between the 1920s to 1960s. This, however, reflects potential yield from the use of high yielding material. The effective commercial yield is considerably lower, as will be seen in a later section.

It should be pointed out that, thus far, attention has centered on Hevea breeding by means of vegetative propagation. Although this remains the principal mode of advance in Hevea breeding, much work has also been directed, mainly by the private sector, to the sexual production of clonal seed. The term clonal seed is frequently used to describe any seed taken from good proved clones. The use of



Source: B. C. Sekhar, "Scientific and Technological Development in the NR Industry," Malaysian Rubber Review, 1 (July 1976), Table 1, p. 26.

Figure 3. Evolution of Planting Materials through Breeding and Selection.

this general term seems to imply that all clonal seeds are valuable planting material, but this is apparently not so.[21]

Only the seed obtained from controlled crossing between selected known parents should be described as legitime seed.[22] Seed from budding trees of which only the mother clone is known with certainty should be described as illegitimate seed. Trees grown from such seed are likely to exhibit considerable variation in yield, owing to the uncertainty of their male parentage.

Although the yields of the best families of legitimate seedlings may be equal to the best proved clones, it would take considerably longer to introduce seedling families of proved value than the odd 15 years required with new clones.[23] This is because even when the value of a family has been established a considerable additional period may be required for raising the large quantities of seeds for planting on a commercial scale. Since speed is of the essence, it was natural that the earliest work of the plant breeder on rubber should be associated with the production of new clones.

The clonal seed sold commercially is seed collected from isolated areas, called "gardens," planted with selected parents, the potential yield of whose progeny is to a greater or less degree

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[21]Edgar, Manual of Rubber Planting (Malaya), 1937, p. 76.

[22]Ibid.

[23]C. E. T. Mann, "The Work of the Botanical Division of the RRI, Planters Bulletin, old series, No. 17 (October 1941), p. 2.

known.[24] By definition, these "isolation garden seed" are illegitimate but they have been found to be suitable for large scale cultivation after exhaustive testing--on a scale comparable to the testing of new clones. This is the type of seed, Prang Besar Isolation Garden (PBIG), which is marketed by Prang Besar Research Station.

As might be expected clonal seedlings, by their nature, are more variable than budded clones, both in their yields and secondary characteristics. They now form only about 5 percent of the estate area under high yielding material. However, about 30 percent of the smallholding high yielding area is estimated to be still under clonal seedlings, largely because smallholders favored the more rapid growth, shorter immaturity, and greater hardiness of the seedling trees. The acreage under clonal seedlings can be expected to rapidly decline as clonal seeds are no longer recommended for replanting by smallholders since 1972.

While the yield advances from using clones and clonal seedlings by the industry have produced spectacular results, one outcome of the heavy reliance on vegetative propagation in breeding and selection work is the problem of "genetic erosion." The 22 Wickham seedlings and later importations introduced into Malaysia apparently came from one particular area in the Central Amazon basin in which the wild trees were only of moderate yields.[25] The stringent selection procedures

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[24] Hevea is largely self-sterile and the seed from polyclonal gardens is generally superior to that from monoclonal gardens. The only important exception is the selfed seedlings from the Tjir 1 clone.

[25] Planters Bulletin, No. 16 (1955), p. 2.

to obtain the relatively small number of "proved" clones planted today, many of which are of related parentage, have led to genetic erosion.[26] Although the selected clones have concentrated genes which contribute to high yield (the main attribute selected by breeders), there is apparently some loss of genes, particularly those conferring resistance to leaf diseases. The fact that yield improvement seems to be levelling out is yet further confirmation of erosion within the limited genetic base of the original Wickham collection.[27]

A somewhat different matter of concern has to do with the fact that most recommended clones perform best on the half-spiral, alternate daily tapping system, S/2.d/2, a corollary of using the S/2.d/2 system in programs of selection. This system is not universally used; in smallholdings, operated by family labor, daily tapping is frequently the practice.

These problems have been recognized by breeders in Malaysia and efforts to overcome some of these constraints have already been incorporated in the long term breeding and selection strategies of the RRIM.[28] They include: widening of the genetic base in general;

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[26]P. R. Wycherley, "*Hevea* Reminiscences," Rubber Research Institute of Malaysia, *Planters Bulletin* (forthcoming).

[27]This has led Wycherley to speculate on the use of clonal seedlings. He estimated that a judicious system of breeding and selection based on hand pollination would have produced seedling families giving yields comparable to those of clones (see Wycherley, Ibid.).

[28]C. Y. Ho, H. Tan, S. H. Ong, M. O. Sultan, and Mohd. Noor B. Abdul Ghani, "Breeding and Selection Strategies at the Rubber Research Institute of Malaysia," paper prepared for Workshop on International Collaboration in Hevea Breeding and the Collection and Establishment of Materials from the Neo-Tropics held in Kuala Lumpur from April 12-16, 1977.

shortening breeding and selection cycles; exploiting synergistic approaches by using suitable crowns; promoting fruit set; broadening the base for field resistance to diseases, particularly to SALB; and improving methods of planting recommendations by taking ecological or environmental factors into consideration. In addition, at a recent breeding workshop the feasibility of sending an expedition to the Amazon basin of Brazil to collect new rubber plants was explored. This was the Workshop on International Collaboration in Hevea Breeding and the Collection and Establishment of Materials from the Neo-Tropics organized by the RRIM and held in Kuala Lumpur from April 12-16, 1977.

Technology Transfer Phases in High Yielding Materials

To determine if the diffusion and development of Hevea has gone through the three "phases of technology" transfer we consider each phase in turn.[29]

Material transfer is characterized by the simple transfer of new materials such as seeds, plants, animals, etc., and the cultural practices associated with these materials. In Hevea this phase can be identified with the collection by Wickham of seeds from the Amazon Basin and the transfer of germinated seedlings from Kew in England to South and Southeast Asia. In Malaysia, as elsewhere, the planting material used during the early years was unselected seedlings obtained from any available source. Initial efforts by planters were mainly confined to agronomic improvements and improved methods of exploitation.

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[29]Hayami and Ruttan, Agricultural Development, pp. 174-76.

Design transfer is characterized by the transfer of information in the form of blue prints and related "soft ware." New plants and animals are subject to systematic test, propagation and selection for eventual adaptation to local conditions. In *Hevea*, this phase is associated with the collection, by the early pioneers, of seeds from mother-trees which displayed superior yielding characteristics. The progress obtained from this crude selection method indicated the potential of using this genotypically heterogenous material for breeding.

Capacity transfer occurs through the transfer of scientific and technical knowledge and capacity. The objective is to institutionalize local capacity for invention and innovation of a continuous stream of locally adopted technology. Increasingly, plants and animal varieties are developed locally to adapt them to local ecological conditions. In *Hevea* this development was not possible until the discovery of the budgrafting technique of vegetative propagation in Indonesia. This relatively simple breeding technique was rapidly diffused to Malaysia and other rubber producing countries. A further advance was the use of sexual reproduction in hand-pollination to produce legitimate progenies. This development opened the way for systematic breeding and selection of *Hevea* to suit the local ecological conditions and factor endowments of the economy.

From the review of the phases of technology transfer in *Hevea* it appears that Malaysia attained the capacity phase about 1928 when the RRIM plant breeder, Morris, made the first series of hand pollination locally. It is now the principal innovator not only of high yielding materials but of all types of *Hevea* technology and knowledge. The implication of this development and viewed in the perspective of the induced developed model is that total returns to rubber research should be high. Before turning to the quantification of returns from rubber investment in Malaysia, it may be of interest to point out that with Hevea the design transfer, and capacity transfer phases have developed largely within the region. It was the result of mutually beneficial technical interchange and cooperation between researchers in the region, particularly Malaysia and Indonesia, nurtured by the importation of scientists and administrators from Britain, Holland, and other European countries. That Malaysia was able to capitalize on the transfer of high yielding materials and human capital makes its experience almost unique among developing countries.

Commercial Yields of Planting Materials

The achievement by the rubber plant breeders and selectionists has certainly been spectacular. They have contributed to the evolution of rubber trees capable of yielding a four-fold increase relative to the unselected seedlings in a period of just over 40 years but they apparently have still some way to go before the "yield summit" is reached. The "yield summit for Hevea, through mutation breeding and tissue culture techniques, has been estimated to be in the region of 9,500 pounds per acre per year.[30]

Be that as it may, the important question is how much of this yield potential gets translated on to the ground. There is controversy on the kind of yield data, experimental or farm level, to use in

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[30] J. K. Templeton, "Where Lies the Yield Summit," Planters Bulletin, No. 104 (1969), p. 224.

measuring the contribution of the new planting materials, which are the product of breeding research. The recent exchange by Ayer and Schuh over this question is a good illustration.[31]

While experimental station or field data would certainly be more reliable than farm level yields to establish the net contribution of new seeds or planting materials to productivity they tend, in practice, to reflect potential rather than effective or realized yields. This is because experimental yield data generally establish yield differentials at an agronomic optimum level of other inputs. If planters apply less of other inputs than do the experiment stations, as is probably the case with many smallholders, experimental station yields would be biased upwards. Further, unlike an annual crop, it is not feasible to maintain experimental plantings of the innumerable Hevea clones that have, at one time or another, been recommended for planting and to keep yield records on each of them for a period of about thirty years. Although the RRIM through its "commercial registration" program has annual yield data up to about 15 years, the information is restricted to a relatively small number of clones planted on the bigger and more progressive estates. In any case, the primary concern in this ex post study of research returns from breeding and selection is with effective or realized yields, not potential yields, from high yielding materials planted on estates and smallholdings. For the expressed purpose at hand, farm level guides are preferred.

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[31]H. W. Ayer and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics 54 (1972): 557-69; G. R. Saylor, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil: Comment," American Journal of Agricultural Economics 56 (1974):171-74.

Farm level or commercial yield figures on an industry wide basis or by subsectors are not available on a clone by clone basis, however. Yields for unselected and high yielding materials separately, and that, too, for estates, have only become available since about 1950. Such yields are of a composite nature, being the aggregate yield of trees of different clones, ages, tapping intensity, managment, etc. They also reflect the long time lag in the breeding cycle and the unevenness in the diffusion of high yielding materials between the different producing subsectors. Since these are matters of direct concern to this study, the critical question is whether reasonable estimates of historical time series yield data by the two categories of planting materials and two producing subsectors can be made. With the data base that has been built up by the Applied Economics and Statistics Division of the RRIM, and with the assistance of colleagues from the various RRIM divisions and the industry the task was carried out. In the process earlier estimates such as that made by the Mudie Mission were used as bench-marks in checking the "reasonableness" of the estimates.

Starting with the estate sector first, yield figures for unselected and high yielding materials have been published by the Department of Statistics in the Rubber Statistics Handbook since 1950. The annual high yielding yields before 1950 were estimated using a regression equation obtained by regressing annual high yielding yields from 1950-73 on high yielding production. Yields of unselected materials were estimated by taking the difference of total estate production and total production of high yielding materials using time series data and dividing the net annual figures by the tapped acreage of unselected materials (Table 9). The resulting figures of observed and estimated commercial estate yields from the use of the two types of planting materials are shown in Table 9, except for 1941 and the Japanese Occupation Period, 1942-45.

The paucity of any kind of smallholder data is well-known. For that reason, the estimates were more difficult to make and are less reliable.

In the absence of any smallholder yield figures by the two kinds of planting materials, the annual yield of high yielding materials was assumed to be 70 percent that of the respective estate high yielding figure.[32] The corresponding yield of unselected materials, Y_U, was estimated as a residual, i.e., by the following simplying approximation:

$$Y_U = \frac{P_T - Y_H \cdot A_H}{A_U}$$

where:

P_T = total smallholder production

Y_H = average annual high yielding materials yield

A_H = mature acreage under high yielding materials

A_U = mature acreage under unselected materials

In lieu of figures on smallholder tapped acreage, estimated mature acreage figures were used. The annual mature acreages of the two

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[32]This figure was used following discussions with colleagues at the RRIM. This was also the figure used in P. O. Thomas, T. H. Tay, and Habibah Suleiman, "The Establishment of an Agro-Economic Norm for Malaysian NR Production," Malaysian Rubber Research and Development Board, Kuala Lumpur, September 1976, p. 61.

Table 9.--Tapped Acreages and Yields of High Yielding and Unselected Materials in Estates and Smallholdings.

Year	Estates						Smallholdings					
	Tapped Acreage (1000 AC)			Yield (LB/AC)			Tapped Acreage (1000 AC)			Yield (LB/AC)		
	Total	HYM	UM	AV	HYM[f]	UM[g]	Total[h]	HYM[i]	UM[j]	AV[e]	HYM[k]	UM[l]
1927	n.a.	n.a.	n.a.	408[d]	480	408	550	--	550	n.a.	--	n.a.
1928	n.a.	n.a.	n.a.	426[d]	491	426	603	--	603	n.a.	--	n.a.
1929	n.a.	n.a.	n.a.	474[d]	502	474	748	--	748	n.a.	--	n.a.
1930	n.a.	n.a.	n.a.	489[d]	513	489	813	--	813	593	--	593
1931	n.a.	14	n.a.	487[d]	525	487	887	--	887	494	--	494
1932	1104	15	1089	483[e]	537	483	995	--	995	399	--	399
1933	1179	21	1158	454[e]	549	453	1013	--	1013	484	--	484
1934	1281	28[b]	1253[b]	455[e]	561	452	1050	--	1050	463	--	463
1935	1475	33	1442	365[e]	574	360	975	1	974	306	402	306
1936	1381	47	1334	375[e]	587	367	1050	2	1048	276	411	276
1937	1338	95	1243	522[e]	600	516	1149	3	1146	362	420	362
1938	1142	101	1041	479[e]	614	466	1132	5	1127	224	430	223
1939	1318	123	1195	413[e]	628	391	1159	7	1152	222	440	221
1940	1381[a]	129[c]	1252	539[e]	642	528	1180	9	1171	404	449	403
1946	n.a.	177	n.a.	n.a.	672	n.a.	1457	27	1430	353	470	351
1947	1417	287	1130	570	687	539	1470	30	1440	435	481	434
1948	1600	332	1268	560	703	528	1548	30	1518	426	492	424
1949	1638	383	1255	550	719	495	1550	34	1516	391	503	388
1950	1647	400	1247	510	711[e]	447[e]	1551	38	1513	457	498	456
1951	1597	378	1219	460	800[e]	355[e]	1553	42	1511	398	560	393
1952	1576	401	1175	480	826	363	1570	46	1524	345	578	338
1953	1615	430	1185	470	799	355	1530	50	1480	339	559	332
1954	1606	411	1195	480	820	350	1531	53	1478	351	574	343
1955	1603	445	1158	492	806	356	1523	56	1467	420	564	414

Table 9.--continued.

Year	Estates						Smallholdings					
	Tapped Acreage (1000 AC)			Yield (LB/AC)			Tapped Acreage (1000 AC)			Yield (LB/AC)		
	Total	HYM	UM	AV	HYM[f]	UM[g]	Total[h]	HYM[i]	UM[j]	AV[e]	HYM[k]	UM[l]
1956	1581	498	1083	497	781	355	1503	58	1445	381	547	374
1957	1538	554	984	536	806	375	1468	63	1405	382	564	374
1958	1486	586	900	587	854	405	1445	69	1376	386	598	375
1959	1422	619	803	641	898	435	1482	76	1406	397	629	384
1960	1368	638	730	677	928	443	1432	99	1333	426	650	409
1961	1332	681	651	720	966	451	1385	126	1259	450	676	427
1962	1315	735	580	746	976	441	1430	159	1271	433	683	402
1963	1314	800	514	782	988	446	1430	220	1210	462	692	420
1964	1305	863	442	818	1010	446	1435	286	1149	491	707	437
1965	1294	918	376	850	1019	438	1513	374	1139	515	713	449
1966	1282	975	307	898	1048	420	1597	487	1110	542	734	458
1967	1279	1035	244	921	1045	395	1669	622	1047	534	731	416
1968	1279	1094	185	986	1082	423	1778	776	1002	594	757	468
1969	1293	1140	153	1028	1117	359	1932	954	978	681	782	582
1970	1291	1165	126	1061	1138	343	2045	1122	923	641	797	452
1971	1270	1174	96	1149	1214	352	2119	1262	857	634	850	315
1972	1232	1166	66	1180	1228	347	2175	1386	789	607	860	163
1973	1209	1162	47	1229	1265	321	2170	1461	709	804	885	637

Notes:

[a]Assuming 66.3 percent of total planted acreage which was the average percentage in 1934-39.

[b]Based on 2.2 percent of HYM acreage and 97.8 percent of UM acreage tapped as a percentage of total tapped acreage. (These were the relative percentage figures of HYM and UM tapped as a percentage of total tapped acreage in 1932-33 and 1935-36).

Table 9.--continued.

Notes (continued):

[c]Based on the total tapped acreage in 1939 and the acreage of HYM new planted in 1933.

[d]Straits Settlement and Federated Malay States only.

[e]Production divided by tapped acreage.

[f]Figures before 1950 were estimated using equation, $Y = 718.630454 \cdot 1.022702^t$
where:
1950-1973, $t = 1$ to 24
1927-1949, $t = -18$ to 0 (For 1941-1945, $t = -4$)

[g]1927-1931 figures were estimated to be the same as the average figures
1932-1949 figures were estimated using $Y = (P_t - Y_h \cdot A_h) \div A_i$
where:
Y = Yield of UM
Y_h - Yield of HYM
P_t = Total production from HYM and UM areas
A_h = Tapped acreage of HYM area
A_i = Tapped acreage of UM area

[h]Total planted acreage less total immature acreage.

[i]Based on new planted and replanted HYM acreage and a 7-year immature period.

[j]Balance of (h) and (i).

[k]Before 1935 it was assumed that there was no HYM acreage being tapped
1935-1973 based on 70 percent of estate HYM yield per acre.

Table 9.--continued.

Notes (continued):

[1]Before 1935 it was assumed to be the same as the average 1935-1973 estimated on the basis of $Y = (P_t - Y_h \cdot A_h) \div A_i$ (Details of the above equation are given in footnote g).

n.a. = not available

Sources: Department of Statistics, Rubber Statistics Handbook (various issues).
Department of Statistics, Malaysia Monthly Statistical Bulletin (various issues).

kinds of planting materials were estimated by assuming a gestation period of 7 years from the time of planting (see Appendix B).

It can be seen from the columns showing yield of unselected materials in Table 9 that the yield levels have declined, particularly after World War II. The main factor for the decline is that with the availability of high yielding materials there was virtually no replacement with unselected materials, particularly on estates. The pace of replacement of unselected seedlings by high yielding materials was hastened with the promulgation of a national replanting program based on the slogan "Replant or die." Consequently, as the acreage of unselected materials has declined, the existing stands were getting progressively older. The corollary is further decline in yields. It is plausible to argue that if high yielding materials were not available, and there had been no official policy to replant only with high yielding materials, the acreage of unselected materials would not have declined so dramatically. The inference is that there may be a downward bias to the yields of unselected materials.

To take account of this possibility, we postulate what might have been the yields if high yielding materials had not been available. In such a situation replanting with unselected materials would have been resorted to. To estimate the yield of unselected materials in the absence of high yielding materials, the maximum yield level was set at 600 pounds per acre per year and an exponential curve was used to reestimate the yields. The details of the estimation procedure are given in Appendix B. Table 10 shows the estimated yields of unselected materials with and without high yielding materials.

Table 10.--Estimated Yields of Unselected Seedling Materials with and without High Yielding Materials.

Year	'With' HYM (Lb/Ac)		'Without' HYM (Lb/Ac) (3)	(3)/(1) (%)	(3)/(2) (%)
	Estate (1)	Smallholding (2)			
1927	408		447	109.56	
1928	426		453	106.34	
1929	474		458	96.62	
1930	489	593	464	94.89	78.25
1931	487	494	469	96.30	94.94
1932	483	399	474	98.14	118.80
1933	453	484	479	105.74	98.97
1934	452	463	483	106.86	104.32
1935	360	306	488	135.56	159.48
1936	367	276	492	134.06	178.26
1937	516	362	496	96.12	137.02
1938	466	223	500	107.30	224.22
1939	391	221	504	128.90	228.05
1940	528	403	507	96.02	125.81
1946		351	526		149.86
1947	539	434	529	98.14	121.89
1948	528	424	532	100.76	125.47
1949	495	388	534	107.88	137.63
1950	447	456	537	120.13	117.76
1951	355	393	539	151.83	137.15
1952	363	338	542	149.31	160.36

Table 10.--continued.

Year	'With' HYM (Lb/Ac)		'Without" HYM (Lb/Ac) (3)	(3)/(1) (%)	(3)/(2) (%)
	Estate (1)	Smallholding (2)			
1953	355	332	544	153.24	163.86
1954	350	343	546	156.00	159.18
1955	356	414	548	153.93	132.37
1956	355	374	550	154.93	147.06
1957	375	374	552	147.20	147.59
1958	405	375	554	136.79	147.73
1959	435	384	555	127.59	144.53
1960	443	409	557	125.73	136.19
1961	451	427	559	123.95	130.91
1962	441	402	560	126.98	139.30
1963	446	420	562	126.01	133.81
1964	446	437	563	126.23	128.83
1965	438	449	565	129.00	125.84
1966	420	458	566	134.76	123.58
1967	395	416	567	143.54	136.30
1968	423	468	569	134.52	121.58
1969	359	582	570	158.77	97.94
1970	343	452	571	166.47	126.33
1971	352	315	572	162.50	181.59
1972	347	163	573	165.13	351.53
1973	321	637	574	178.82	90.11

Source: See Appendix B.

CHAPTER IV

METHODOLOGICAL FRAMEWORK FOR QUANTIFYING RESEARCH RETURNS

To better understand the process of measuring returns from research, it is helpful to view research as a production activity. The inputs of research then include banks of genetic materials, laboratory facilities, experimental fields, and various mixes of "scholarly capital," while the end-product or output is new information (knowledge or technology). A part of the research output is evidently a final product--in the sense that it is generated only to satisfy a researcher's curiosity for new knowledge. The major concern, however, will be with "organizing that research in which the new knowledge so generated is an input into the development process and directed to the attainment of larger goals."[1]

A basic characteristic of knowledge is that it meets the dual attributes of a public good, namely, jointness of supply and non-excludability. This implies that research benefits in general are not easily or fully captured by the individual or firm incurring the cost

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[1] G. E. Schuh, "Some Economic Considerations for Establishing Priorities in Agricultural Research," paper presented at the Ford Foundation seminar of program advisers in agriculture, Mexico City, November 6-10, 1972, p. 6.

of producing them. Left to its own devices the market place will not normally provide adequate incentive or reward for the production of new knowledge.

It is precisely because of the non-excludability or free-rider problem associated with public goods that so much of agricultural research has become the responsibility of public organizations. It is for this reason that rubber research in Malaysia and elsewhere is mainly in the hands of public or producer-supported research institutes. Where private research organizations exist, such as the Prang Besar Research Station in Malaysia, their research work is mainly on the breeding and selection of planting materials for sale and/or on specialized lines of work, such as soil investigations, to supplement the more general work of the public or quasi-governmental institutes like the RRIM. This is because the new knowledge generated from such research can be more readily embodied in proprietary products.

The public good attributes of new knowledge are reinforced by its "indestructibility," i.e., utilization of the information will in no way reduce its availability to other consumers or imbibers of knowledge. However, knowledge, like ordinary goods, is subject to obsolescence or non-biological decay.

In agriculture, the research process can get even more complex since it involves complementary and synergetic relationships among a variety of scientific disciplines. Agricultural and therefore rubber research is part of a continuum--a succession of discoveries and a clarification of processes that help solve future problems.[2] Viewed

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[2] I. Arnon, The Planning and Programming of Agricultural Research (Rome: Food and Agricultural Organization, 1975), p. 62.

in this light, the output of agricultural research and, as we have noted, rubber research is a joint product of many disciplines and research divisions. For the reasons mentioned, the problems of quantifying agricultural research returns are considerable.

Rates of return have been variously estimated, depending on the analyst's knowledge or understanding of the intricacies of the agricultural research process. Some of the estimates have been based on entire research programs. Others take only successful projects. Moreover, as Arndt and Ruttan, quoting Webster, pointed out, many studies have considered only direct costs, leaving out extension and associated costs of supportive programs, thereby omitting or reporting only part of the costs of research implementation.[3]

In addition, a systematic analytic framework is necessary to ensure that the results of computation of rates of return to investment in agricultural research will be meaningful to policy makers. Otherwise, the available estimates can be abused in policy discussions. One illustration of this, according to Evenson, is the inconsistent citation of extraordinary high rates of return--especially the oft-quoted 700 percent return on hybrid corn research. This has left the impression that the estimates themselves are subject to such a degree of error that only those above 100 percent or so are really significant.[4]

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[3]T. M. Arndt and V. W. Ruttan, "Valuing the Productivity of Agricultural Research: Problems and Issues," in Resource Allocation and Productivity in National and International Agricultural Research, eds. Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977), p. 4.

[4]R. E. Evenson, "Comparative Evidence on Returns to Investment in National and International Research Institutions," in Resource

Review of Methodological Framework

In the main, the methodological framework used in the measurement of returns from agricultural research originated from the University of Chicago and bear the deep imprints of T. W. Schultz and Zvi Griliches.

The earliest approach, often associated with Schultz, attempted to measure the savings in cost or value of inputs saved as a corollary of research.[5] This approach, however, has certain inherent drawbacks, not least of which is the expected bias to the returns relative to the costs. Not only is there a likelihood that the increase in the educational level of farm people may have had some effect in raising productivity but, as Schultz himself recognized, part of the improvement in production techniques should be attributed to private research and extension.[6] However, Schultz also pointed out that some public expenditures may well be allocated to activities not directed at producing and distributing new production techniques. Consequently, these activities would not be reflected in the productivity ratio--causing in effect a downward bias to the return side. Moreover, it is not too clear how activities which increase the quality of farm output are reflected in the productivity ratio.

Allocation and Productivity in National and International Agricultural Research, eds. Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977), p. 239.

[5]T. W. Schultz, Economic Organization of Agriculture (New York: McGraw-Hill, 1953), pp. 119-22.

[6]W. Peterson and Y. Hayami, "Technical Change in Agriculture," Staff Paper P73-20, Department of Agricultural and Applied Economics, University of Minnesota, p. 38.

Most recent studies have, therefore, turned to the direct benefit cost approach, also known as the index number approach. This was first employed by Griliches in his pioneering hybrid corn study. The other main approach uses the production function. Sometimes a combination of both approaches may be used.[7]

The first approach involves a number of stages in the computation. They include estimation of (1) gross benefits, (2) research costs, and (3) rate of return over time.

The estimation of gross research benefits makes use of the concept of "economic surplus," first outlined by Marshall about a hundred years ago, to measure the extra value of output obtained from a given quantity of more efficient resources. In this case (see Figure 4), the aggregate supply function for the product in question is shifted downward in proportion to the change in productivity arising from agricultural research in that product. The benefits are then measured as the area between the original and the shifted supply schedules, and below the demand function. The benefits are interpreted to be a change in consumer and producer surplus.

Apart from the difficulties in deciding on and obtaining the relevant research expenditure data (Griliches used only the direct cost of hybrid corn research), a major issue is its validty in measuring non-marginal changes associated with agricultural research.[8]

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[7]For an excellent review of these approaches, see Peterson and Hayami, "Technical Change in Agriculture," pp. 36-47.

[8]A. A. Schmid, "Nonmarket Values and Efficiency of Public Investments in Water Resources," American Economic Review 57 (May 1967): 158-68.

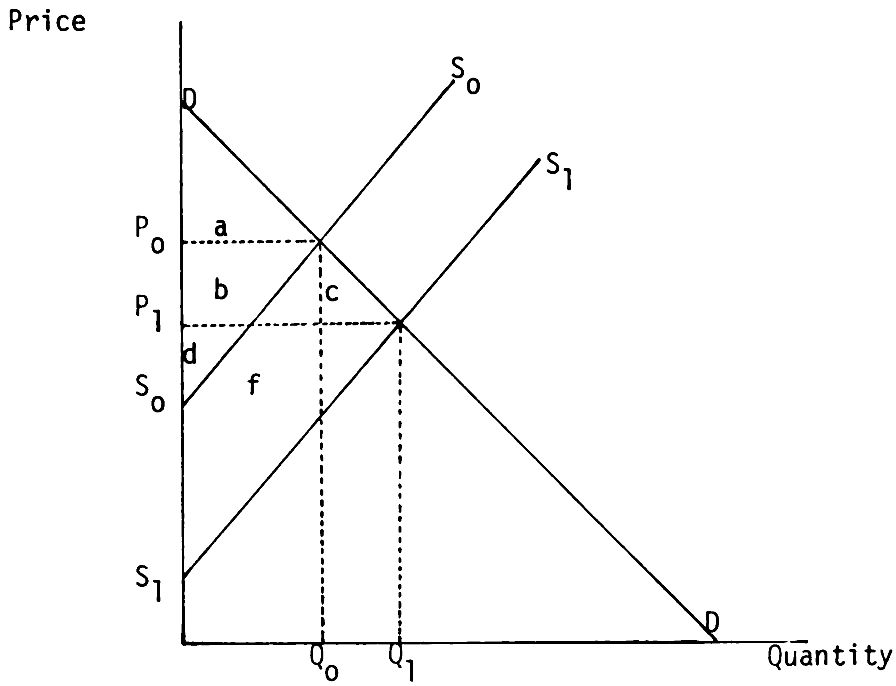

Figure 4. Model for Estimating Research Benefits.

It does seem rather implausible that hybrid corn had no significant effect on the prices of other goods as Griliches apparently assumed. The demand curve for corn today is a function of other goods. If hybrid corn were not available and corn prices were higher, it may be expected that the demand curves and prices for other goods would be affected. This in turn would affect the demand for corn, and subsequently, the consumer surplus. With rubber, however, this may not be so serious a problem since consumer expenditure on rubber products represents an insignificant portion of total consumer expenditures, and raw rubber accounts for such a small proportion of the sales value of most rubber products. Rubber has always been a minor material input accounting for less than 4 percent of total costs in the automobile industry, which traditionally has absorbed about 65 percent of annual rubber output.[9]

Another problem with the direct benefit cost approach is that it typically assumes that the research improvement is potentially available forever.[10] Thus the value of its replacement must be measured by the increase in benefits over what was previously possible. Three situations in which the assumption of perpetual availability of an improvement may not be reasonable, mentioned by Allen,[11] are:

1. when biological decay say of a new seed variety sets in;
2. where the output of a commodity declines over time through non-use; and
3. when obsolescence or non-biological decay sets in.

Other shortcomings that might account for the unusually high returns from agricultural research have been suggested by Hertford and Schmitz.[12] These include: not talking into account the fact that a commodity may be traded, international spillover effects of research, confusion over the effects of research on intermediate and final

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[9] T. R. McHale, "Changing Technology and Shifts in the Supply and Demand for Rubber: An Analytical History," Malayan Economic Review 9 (1964):31.

[10] P. G. Allen, "Evaluation of Research Expenditures in California Agriculture" (Ph.D. dissertation, University of California, 1972), p. 22.

[11] Ibid.

[12] R. Hertford and A. Schmitz, "Measuring Economic Returns to Agricultural Research," in Resource Allocation and Productivity in National and International Agricultural Research, eds. Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977), pp. 148-67.

products, omission of costs of resource unemployment induced by research, and inappropriate assigning of welfare weights to gains and losses from research.

The second main approach makes use of an agricultural production function estimated from cross-section data which includes research as a separate variable. The procedure has been developed and extended by the recent work of Evenson.[13] The main advantage of using a production function is that the marginal product of research can be computed directly from it. But as Peterson and Hayami have pointed out, it is not strictly correct to interpret marginal products from agricultural research as marginal rates of return since there is a lag between the research input and the bulk of its output.[14] Evenson (1968) found a lag of between 6 to 7 seven years but the length of the lag would, of course, depend on the nature of the research problem and the agricultural commodity involved.[15] Perhaps the main constraint associated with the use of the production function approach has to do with "severe data problems," unless based on farm surveys, and the related problem of extrapolating the results to the national or international level.[16]

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[13]Robert E. Evenson and Yoav Kislev, Agricultural Research and Productivity (New Haven and London: Yale University Press, 1975).

[14]Peterson and Hayami, "Technical Change in Agriculture," p. 42.

[15]Robert E. Evenson, "The Contribution of Agricultural Research and Extension to Agricultural Production" (Ph.D. dissertation, University of Chicago, 1968).

[16]Dalrymple, "Evaluating Impact of International Research on Wheat and Rice Production in Developing Nations," p. 194.

Procedure Adopted in Estimating Benefits from Rubber Research

The present effort will attempt to measure not only the benefits from rubber research to consumers and producers but also the distribution of benefits to the two producing subsectors, and between factors of production. As such some variant of the economic surplus framework is, perhaps, the most practicable procedure.

Although there is still controversy over its use (most recently brought out by Wise, 1975, and Lindner and Jarrett, 1977),[17] Hertford and Schmitz, after a careful review of the literature, have concluded that "most shortcomings of studies of returns to research arise not from the concept of economic surplus but from overlooking or mistreating practical characteristics of the real world."[18] Cognizance will be taken of the shortcomings, some of which have already been indicated, in the present study.

Gross Benefits

The benefits from rubber research can be illustrated by means of Figure 4. As shown in the diagram, P_0 is the equilibrium price associated with D, a normally sloped demand curve, and S_0, an initial supply curve prior to any technological change, i.e., before high yielding materials were available. S_1 is the new position of the

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[17]W. S. Wise, "The Role of Cost-Benefit Analysis in Planning Agricultural R & D Programs," Research Policy 4 (July 1975):246-61; R. K. Lindner and F. G. Jarret, "Measurement of the Level and Distribution of Research Benefits," paper presented at the 21st Annual Conference, Australian Agricultural Economics Society, Brisbane, February 8-10, 1977.

[18]Hertford and Schmitz, "Measuring Economic Returns to Agricultural Research," p. 157.

supply curve and P_1 the new price following the technological change. The consumers' surplus prior to the technological shift is shown by a. Following the shift, it is a+b+c. The net gain to consumers as a result of the shift in the supply curve from S_0 to S_1 is b+c. It can be similarly shown that producers' surplus before and after the shift amounted to b+d and f+d, respectively. The net gain to producers is then f-b. The total gains by consumers and producers following the technological change can now be added: b+c+f-b=c+f. This area has been shown to be approximately equal to

$$kP_1Q_1(1+\tfrac{1}{2}k/n+e)$$

where k is the shift factor defined as the percentage increase in production attributable to research (the horizontal distance between the two supply curves divided by the quantity of final production, Q_1); P_1 is the new price after the supply shift; and n and e are the price elasticities of demand and supply, respectively.[19]

A primary objective of this study is to consider the redistribution of research benefits between producers and consumers, and different classes of producers. It is, therefore, desirable to disaggregate the formula into its primary components, consumers' and producers' surplus. This has been shown by Hertford and Schmitz to be as follows[20]:

$$\text{Consumers' surplus} = \frac{kP_1Q_1}{n+e}(1 - \frac{1}{2}\frac{k}{n+e})$$

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[19]Ibid., p. 155.

[20]Ibid.

$$\text{Producers' surplus} = kP_1Q_1\left\{1 - \frac{1}{n+e}\left[1 - \frac{1}{2}k\left(\frac{2n+e}{n+e}\right)\right]\right\}$$

Although the aforementioned formulations postulate a linear supply and demand relationship, as a matter of convenience, more complicated formulations based on non-linear supply and demand relationships such as that proposed by Ardito-Barletta (1971)[21] apparently provide substantially similar estimates of research benefits, according to Hertford and Schmitz. While this is true from the formulation that Hertford and Schmitz used, which was taken from the appendix of Barletta's study, this is not the exact formulation that Barletta himself used in his text.[22] The main reason they suggest is that in all formulations the critical determinant of the value of the benefits derived from research is simply kP_1Q_1 or the percentage change in the value of production attributable to research [italics in original].[23]

Data Used and Sources

To estimate benefits from rubber research by the procedure outlined, we need, in addition, information on the price elasticities

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[21] Nicolas Ardito-Barletta, "Costs and Social Benefits of Agricultural Research in Mexico" (Ph.D. dissertation, University of Chicago, 1971), pp. 79-84.

[22] In the text, the two shift factors, k, in the formula are not the same; the k in the first term is the same one used by Hertford and Schmitz, but the other k in the formulation is not weighted by the percentage of area planted to the improved seed over total planted area. This can lead to greater differences under certain conditions than suggested by Hertford and Schmitz.

[23] Hertford and Schmitz, "Measuring Economic Returns to Agricultural Research," p. 156.

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of supply and demand (e and n), and the rate of shift in the production function (k), rubber prices and the consumer price index.

Supply and Demand Parameters

In spite of the fact that the supply and demand elasticities are key parameters in the estimating procedure, it is often not clear from the studies that have been made whether the values quoted are short or long run elasticities. Indeed, both types of elasticities seem to have been used. Griliches used a long-run supply elasticity of 0.2 for corn that was estimated by Nerlove.[24] A recent study by Evenson, Flores, and Hayami, used a mixture of long and short run elasticities.[25] The price elasticity of demand for rice used was a short run one, while the supply elasticity was the mean of the short and long run price elasticities of supply.

The less than systematic use of supply and demand parameters reflects in part the paucity of reliable estimates. The other factor may have to do with the fact that "these elasticities have only a second-order effect, and hence different reasonable assumptions about them will affect the results very little."[26] In their study of cotton research in Brazil, Ayer and Schuh found, in calculating internal rates

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[24]Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy 66 (October 1958):419-31.

[25]R. E. Evenson, P. M. Flores, and Y. Hayami, "Costs and Returns to Rice Research," Conference on Economic Consequences of New Rice Technology, Resource Paper No. 11, The International Rice Research Institute, Laguna, Philippines, December 13-16, 1976, p. 16.

[26]Griliches, "Research Costs and Social Returns: Hybrid Corn," p. 422.

of return to cotton research that the results were changed only a little by different assumptions about the respective price and supply elasticities.[27] In addition, the Statistics Division of the Ministry of Overseas Development has reviewed and summarized calculations based on a number of earlier studies to show that when the elasticity of demand is within the range of -0.5 to -1.85 changes in the elasticity of supply make little difference (less than 5 percent) in the amount of benefit.[28] As Dalrymple has noted "these findings suggest that it is possible to be flexible and pragmatic in obtaining estimates of k, and that introductory analyses might leave out estimates of E_s and E_d."[29]

All statistical evidence on the short run response of Malaysian rubber production to price indicates that it is price inelastic. Chan, using regression analysis, with annual production as the dependent variable and price variously defined (current, lagged by the immature period, 3-year moving average) as the independent variable found that current production on estates was not significantly related to current price.[30]

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[27] Ayer and Schuh, "Social Rates and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo," pp. 557-69.

[28] "A Note on the Use of Commodity-Based Studies in Estimating the Pay Off to Investment in Research," Ministry of Overseas Development, Statistics Division, London, September 1974.

[29] Dalrymple, "Evaluating Impact of International Research on Wheat and Rice Production," p. 197.

[30] F. K. Chan, "A Preliminary Study of Supply Response of Malayan Rubber Estates between 1948 and 1959." Malayan Economic Review 7 (October 1962):77-94.

The lack of response to price was attributed to irreversibility of supply--once the trees had been planted and other fixed costs incurred, variable costs were low. A second study by Chan, the results of which were reported by Wharton, used monthly data and related estate production to mature acreage, composition of trees and a trend variable in addition to current price.[31] Again, estate production was found to be price unresponsive. A simple equation with a 3-month moving average price was used for the smallholder data. In this case, output was significantly responsive to price, and coefficients of determination were high, indicating that price changes did explain a large part of the variation in smallholder output. Smallholder price elasticities during rising prices ranged from 0.13 to 0.37, and between 0.22 and 0.23 during falling prices, with all coefficients highly significant.

A 1965 study by Stern using multiple regression single equation models and quarterly data for the period 1953-60 confirmed the earlier finding that estate production was totally unaffected by current rubber prices.[32] For smallholders, production was somewhat more responsive to the current price of rubber. The estimated short run price elasticity of supply was 0.2. A more sophisticated study by Cheong using a dynamic model and quarterly data, again, found that the price elasticity of rubber supply was higher for smallholdings, around 0.25,

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[31] C. R. Wharton, Jr., "Rubber Supply Conditions: Some Policy Implications," in The Political Economy of Independent Malaya, ed. T. H. Silcock and E. K. Fisk (Berkeley: University of California Press, 1963).

[32] R. H. Stern, "Malayan Rubber Production, Inventory Holdings, and Elasticity of Supply," Southern Economic Journal 31 (April 1965): 314-23.

against approximately 0.05 for estates.[33] The most recent study by Chow using monthly data from January 1956 to October 1974, and ordinary least squares regressions obtained results that were once again in general agreement with those of previous estimates.[34] The estimated smallholder yearly elasticities of supply relative to annual average prices ranged from 0.12 in 1956 to a maximum of 0.51 in 1972, but dropped to 0.27 in 1973. For estates the range was from 0.052 in 1956 to a maximum of 0.065 in 1960; declining thereafter.

From the empirical studies on the price responsiveness of rubber production in Malaysia, price does not seem to influence output significantly. Estate rubber is almost perfectly inelastic. Even allowing for a seven year lag to alter capacity, supply seems to be quite price inelastic. The relatively long period required to change capacity and composition for any desired increases in production in response to higher prices will tend to make the long run supply inelastic. Evidently, decisions to alter capacity with such a long-lived capital asset cannot be lightly made and the changes in productive capacity in any year are small relative to the total capacity. Further, the long run adjustment by reducing capacity, i.e., going out of rubber altogether, faces difficulties since such a step often

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[33] K. C. Cheong, "An Econometric Study of the World Natural and Synthetic Rubber Industry" (Ph.D. dissertation, University of London, 1972), p. 148.

[34] C. S. Chow, "Some Aspects of Price Elasticities of Rubber Production in Malaysia," International Rubber Conference, Reprint, The Rubber Research Institute of Malaysia, Kuala Lumpur, October 1975.

includes sizable capital losses represented by the future income stream of the stand.

Although short run adjustments to price by smallholders seem to be less rigid than estates, price responsiveness is still inelastic. For reasons already given in respect of estates, the long run supply response of smallholders can also be expected to be price inelastic.

The expected lack of long run price responsiveness was supported by empirical evidence provided by Cheong, who found long run price elasticities of supply of 0.08 for estates and 0.73 for smallholders, respectively.[35] A more recent study by Behrman, using a log-linear supply function found no evidence that world long run price elasticity was statistically significant.[36]

A plausible explanation for the lack of differences between short run and long run price elasticities of supply may have to do with the use of quarterly or annual data of an aggregate type in studies of short run responses to price. According to Wharton, such aggregate data in fact represent a mixture of both short and long run.[37]

The Marshallian-Cournot distinction as to length of run is that the short run corresponds to that period of time during which

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[35]Cheong, "Econometric Study of World Natural and Synthetic Rubber Industry," p. 251. Similarly, I. B. Teken found that "even in the long-run the production or supply schedule of the rubber estates in Indonesia, is for all practical purposes, perfectly inelastic"--see his study on "Supply of and Demand for Indonesian Rubber" (Ph.D. dissertation, Purdue University, 1971), p. 73.

[36]Jere Behrman, "Mini Models for Eleven International Commodity Markets," paper presented for United Nations Conference on Trade and Development, December 1975, p. 10.

[37]Wharton, "Rubber Supply Conditions," pp. 140-42.

productive capacity of a particular firm cannot be changed and during which response can occur only by changing the level of use of variable factors in combination with the fixed stock or productive capacity. Given the technology of rubber production, the fixed productive capacity for an individual firm is, therefore, that period of time during which the firm is unable to change the number of mature trees capable of being tapped. The long run is a sufficiently long period to allow new trees to come into tapping.

With a tree crop like rubber, however, productive capacity is changing all the time--new mature acreage from new planting and replanting, coming into production as well as old mature acreage (replantings and losses) going out of production. Mature acreage is a function of both lagged and current variables. Increases in acreage today are the result of lagged decisions made seven years ago, while losses out of mature acreage are the result of current decisions. All these three elements are in turn functions of a wide range of expectational variables of an economic and non-economic nature--expected future prices of natural and synthetic rubber, expected production of synthetic, expected future costs of production, expected future prices of competing crops such as oil palm, cocoa, etc. Therefore, to use annual or quarterly production data is in fact to measure an amalgam of short run and long run supply price responses.

In this study, two sets of price elasticities of supply, one each for the two producing subsectors, will be used in computing gross research benefits. The supply response of estates to price both in the short and long run is assumed to be perfectly inelastic. For smallholders, two price elasticities, a low of 0.25 and a high of 0.5 will be used.

There is some disagreement among scholars on the magnitude of the short run price elasticity of demand for rubber. A number of earlier econometric studies have found the world demand for natural rubber to be highly inelastic and not significantly different from zero.[38] Other studies by UNCTAD and the World Bank reported estimates which while relatively small or inelastic, are nevertheless, significant. Brown reported that using annual data, UNCTAD, in an unpublished 1968 study, estimated price elasticities of demand, presumably short run, to be between -0.53 and -0.58.[39] More recently, Brown, on the basis of "empirical tests and inferential reasoning of other studies" came up with a monthly demand elasticity of -0.2.[40] The World Bank reported that the price elasticity of demand for rubber, again, presumably short run, varied from a low of -0.25 and a high of -0.6.[41]

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[38] Teken, "Supply of and Demand for Indonesian Rubber," p. 97; Cheong, "Econometric Study of World Natural and Synthetic Rubber Industry," p. 148; and A. J. Reutens, "An Econometric Analysis of the International Rubber Economy" (Ph.D. dissertation, University of Illinois, 1974), p. 119.

[39] C. P. Brown, "International Commodity Control through National Buffer Stocks: A Case Study of Natural Rubber," Journal of Development Studies 10 (1974):200.

[40] C. P. Brown, Primary Commodity Control (Kuala Lumpur: Oxford University Press, 1975), p. 273.

[41] World Bank, Primary Forecast for Major Primary Commodities, Report No. 814, July 1975, Table 20, p. 36.

Although Cheong found all price elasticities of world demand to be small and insignificant in the short run, they amounted to roughly 0.2 in the long run.[42]

The available evidence, albeit inconclusive, seems to suggest that both long and short run price elasticities of demand for rubber to be inelastic and largely invariant in size. This may well be because the demand for rubber is a derived demand for a raw material input which normally constitutes a small proportion by value of the final product. For the present purpose, the World Bank figures will be taken to be representative of the price elasticities of world demand for natural rubber.

At this point it should also be pointed out that even if the world demand for natural rubber were price inelastic, the demand schedule facing Malaysia need not be so. In this study, the relevant demand parameter is the demand elasticity for Malaysian rubber, which can be expected to be elastic. This is because Malaysia is only one of a number of producers of natural rubber and consumers can easily substitute Indonesian, Thai, or Ceylonese rubber for Malaysian rubber. Since Malaysia is the biggest producer, producing about 40 percent of world natural rubber supply, the elasticity of demand facing Malaysian production will be correspondingly lower than that of other producers with smaller shares of the market.

Mention should also be made of the fact that the development of synthetic rubber after World War II has probably reduced the

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[42] Cheong, "Econometric Study of World Natural and Synthetic Rubber Industry," p. 148.

inelasticity of the demand schedule for natural rubber, i.e., by increasing the elasticity of substitution between natural and synthetic rubber.

A rough estimate of the demand for Malaysian rubber can be made by the use of the following formulation, adapted from Stigler (1953)[43]:

$$N_M = \frac{D}{E_M} N_D - \frac{E_O}{E_M} N_O$$

where:

N_M = price elasticity of demand for Malaysian rubber

N_D = price elasticity of world demand for rubber

N_O = price elasticity of rubber supply from other rubber producing countries

D = total quantity of world demand for rubber

E_M = quantity of rubber in the world market supplied by Malaysia

E_O = quantity of rubber in the world market supplied by other countries

The estimated values for the elasticity of demand for Malaysian rubber, assuming -0.25 and -0.6 as the elasticity of world rubber demand, 0.2 as the price elasticity of supply for other rubber producing countries, and that Malaysia produces 40 percent of world natural rubber supply, are approximately -0.9 and -1.9. To facilitate ease of calculations they are rounded to -1.0 and -2.0. An additional value of -0.5 will be used in the sensitivity analyses since it is recognized that this method can only provide a very gross estimate of price elasticities of demand for Malaysian rubber.

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[43]George J. Stigler, The Theory of Price (New York: Macmillan, 1953), p. 301.

Shift Factor

There is apparently no easy, straightforward, or most recommended way of measuring the shift parameter, k, of the supply curve attributable to research.[44] It has been estimated, for example, on the basis of essentially an educated guess by Griliches (15 percent) and de Castro (10 percent), as a shift in the long run supply curve by Peterson, on the basis of estimates of farm level production functions by Ardito-Barletta, and from experimental yield data by Ayer and Schuh. Hertford incorporated yield differences estimated from on-farm trials run by the research program itself into estimates of the shift factor.

It was earlier mentioned that there is disagreement on what data, experimental or farm-level, to use. The main issue apparently concerns whether experimental station data overestimate farm-level yields, and the accuracy or quality of historical farm-level yields (see the recent exchange between Ayer and Schuh, and Saylor on the subject).[45]

For reasons discussed earlier, the tact adopted here is to use commercial or farm-level yield data rather than experimental station data in estimating the shift factor associated with rubber breeding research. To reiterate, it is because commercial yield data reflect the effect rather than the potential gains from the use of the improved

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[44]Dalrymple, "Evaluating Impact of International Research on Wheat and Rice Production," p. 196.

[45]Ayer and Schuh, "Social Rates and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo," pp. 557-69; Saylor, "Social Rates of Return and Other Aspects of Agricultural Research: Cotton Research in Sao Paulo," pp. 171-74.

or high yielding materials, and because "reasonable" estimates of commercial yields for the two producing subsectors can be made.

The shift factor, k, can then be estimated on an annual basis, using essentially the same procedure adopted by Akino and Hayami (1977) in deriving the shift factor for rice in Japan.[46]

$$k = \frac{Y_H - Y_U}{Y_H} \left(\frac{A_H}{A_T}\right)$$

where:

Y_H = yield of high yielding materials

Y_U = yield of unselected materials

A_H = tapped acreage of high yielding materials

A_T = total tapped acreage of all planting materials

The estimated shift factors for estates and smallholdings are shown separately in Table 11. The table also depicts values of k for the two subsectors when the yields of unselected materials were adjusted for possible downward bias due to the post-War replanting program or scheme. As may be expected, the k values in the "without high yielding

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[46] M. Akino and Y. Hayami, "Organization and Productivity of Agricultural Research Systems in Japan," in Resource Allocation and Productivity in National and International Research, eds. Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977), p. 55. It is interesting to note that most practitioners have used Y_H rather than Y_U as the denominator in estimating k, although Carr and Myers (1973) suggested using Y_U--see C. Carr and R. H. Myers, "The Agricultural Transformation of Taiwan: The Case of Ponlai Rice, 1922-42," in Technical Change in Asian Agriculture, ed. R. T. Shand (Canberra: Australian National University Press, 1973), p. 37. The choice of which yield figure to use in the denominator, traditional or new variety, can affect the magnitude of k. In practice, of course, there have been few actual estimates of k. Griliches simply assumed, using some industry estimates, that hybrid corn yields were 15 percent higher than for open-pollinated varieties, as did Carr and Myers.

Table 11.--Shift Factor for Estates and Smallholdings.

Year	With High Yielding Material						Without High Yielding Material					
	Estates			Smallholdings			Estates			Smallholdings		
	k* (%)	ρ (%)	k*ρ (%)	k* (%)	ρ (%)	k*ρ (%)	k* (%)	ρ (%)	k*ρ (%)	k* (%)	ρ (%)	k*ρ (%)
1932	10.056	1.359	0.137	--	0	--	11.732	1.359	0.159	--	0	--
1933	17.486	1.781	0.311	--	0	--	12.750	1.781	0.227	--	0	--
1934	19.430	2.186	0.425	--	0	--	13.904	2.186	0.304	--	0	--
1935	37.282	2.237	0.834	23.881	0.103	0.024	14.983	2.237	0.335	-21.393	0.103	-0.022
1936	37.479	3.403	1.276	32.847	0.190	0.062	16.184	3.403	0.551	-19.708	0.190	-0.038
1937	14.000	7.100	0.994	13.810	0.261	0.036	17.333	7.100	1.231	-18.095	0.261	-0.047
1938	24.104	8.844	2.132	48.140	0.442	0.213	18.567	8.844	1.642	-16.279	0.442	-0.071
1939	37.739	9.332	3.522	49.773	0.604	0.301	19.745	9.332	1.843	-14.545	0.604	-0.087
1940	17.757	9.341	1.659	10.245	0.763	0.078	21.028	9.341	1.964	-12.918	0.763	-0.098
1946	21.543[a]	20.254[a]	4.363[a]	25.319	1.853	0.469	23.435[b]	20.254[a]	4.747[b]	-11.915	1.853	-0.221
1947	21.543	20.254	4.363	9.771	2.041	0.199	22.999	20.254	4.658	-9.979	2.041	-0.204
1948	24.893	20.750	5.165	13.821	1.938	0.268	24.324	20.750	5.047	-8.130	1.938	-0.158
1949	31.154	23.382	7.285	22.863	2.194	0.502	25.730	23.382	6.016	-6.163	2.194	-0.135
1950	37.131	24.287	9.018	8.434	2.450	0.207	24.473	24.287	5.944	-7.831	2.450	-0.192
1951	55.625	23.669	13.166	29.821	2.704	0.807	32.625	23.669	7.722	3.750	2.704	0.101
1952	56.053	25.444	14.262	41.522	2.930	1.217	34.383	25.444	8.748	6.228	2.930	0.182
1953	55.569	26.625	14.796	40.608	3.268	1.327	31.915	26.625	8.497	2.683	3.268	0.087
1954	57.317	25.592	14.668	40.244	3.462	1.393	33.415	25.592	8.551	4.878	3.462	0.169
1955	55.831	27.760	15.499	26.596	3.677	0.978	32.010	27.760	8.886	2.837	3.677	0.104
1956	54.545	31.499	17.181	31.627	3.859	1.220	29.577	31.499	9.317	-0.548	3.859	-0.021
1957	53.474	36.021	19.262	33.688	4.292	1.446	31.514	36.021	11.351	2.128	4.292	0.091
1958	52.576	39.435	20.733	37.291	4.775	1.781	35.129	39.435	13.853	7.358	4.775	0.351
1959	51.559	43.530	22.444	38.951	5.128	1.997	38.196	43.530	16.627	11.765	5.128	0.603
1960	52.263	46.637	24.374	37.077	6.913	2.563	39.978	46.637	18.645	14.308	6.913	0.989
1961	53.313	51.126	27.257	36.834	9.097	3.351	42.133	51.126	21.541	17.308	9.097	1.575
1962	54.816	55.894	30.638	41.142	11.119	4.575	42.623	55.894	23.823	18.009	11.119	2.002
1963	54.858	60.883	33.399	39.306	15.385	6.047	43.117	60.883	26.251	18.786	15.385	2.890
1964	55.842	66.130	36.928	38.190	19.930	7.611	44.257	66.130	29.268	20.368	19.930	4.059
1965	57.017	70.943	40.449	37.027	24.719	9.153	44.553	70.943	31.607	20.757	24.719	5.131
1966	59.924	76.053	45.574	37.602	30.495	11.467	45.992	76.053	34.979	22.888	30.495	6.980
1967	62.201	80.923	50.335	43.092	37.268	16.059	45.742	80.923	37.015	22.435	37.268	8.361
1968	60.906	85.536	52.096	38.177	43.645	16.662	47.412	85.536	40.554	24.835	43.645	10.839
1969	67.860	88.167	59.830	25.575	49.379	12.629	48.970	88.167	43.176	27.110	49.379	13.387
1970	69.859	90.240	63.041	43.287	54.866	23.750	49.824	90.240	44.961	28.356	54.866	15.558
1971	71.005	92.441	65.638	62.941	59.556	37.486	52.883	92.441	48.886	32.706	59.556	19.478
1972	71.743	94.643	67.899	81.047	63.724	51.646	53.339	94.643	50.481	33.372	63.724	21.266
1973	74.625	96.112	71.723	28.023	67.327	18.867	54.625	96.112	52.501	35.141	67.327	23.660

[a]The value of k, ρ and kρ for 1946 are assumed to be the same as 1947.

[b]Based on 1947 figures.

k*(%) = [(YH-YL)/YH]100
ρ(%) = (AH/AT)100
k=k*ρ(%) = [(YH-HL)/YH)(AH/AT)100

material" situation are generally lower since in this case annual yields of unselected materials would be relatively higher than the figures obtained in practice.

Rubber Prices

In valuing estate and smallholding rubber production, the f.o.b. prices of first grade and third grade ribbed smoked sheets (RSS), respectively, were used. This is because the bulk of estate and smallholding rubber is graded RSS 1 and RSS 3, respectively.

It should be mentioned that while much of the rubber produced is still processed and marketed in the traditional sheet form, an increasing quantity of "block" rubber is now produced and marketed under the Standard Malaysian Rubber (SMR) Scheme, first implemented in 1965.[47] Since there is generally a premium on SMR grades over RSS grades, the use of RSS prices implies undervaluation of the rubber produced by both estates and smallholdings (see Appendix C on prices of RSS and SMR grades).

Consumer Price Index

The Malaysian cost-of-living index in the post-War period is apparently one of the most stable in the world and it would, probably, be sufficient to use historical figures in the computations made without significant differences in the results. On grounds of methodological purity, however, it would be better to deflate the historical data.

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[47]In 1973, about 30 percent of Malaysian rubber exported was in the form of SMR. For an account of the SMR Scheme, see T. Y. Pee and Ani Arope, ed., <u>Rubber Owners Manual</u> (Kuala Lumpur: RRIM, 1976).

Table 12.--Consumer Price Indices, Retail Price Indices and Cost of Living Indices in Peninsular Malaysia.

Year	Consumer Price Indices[1]	Cost of Living Indices of Clerical Grades[2]	Retail Price Indices[3]	Consumer Price Indices[4]
	(1963 = 100)	(1939 = 100)	(1959 = 100)	(1967 = 100)
Before 1942	(22.9)[a]			
1942-46	n.a.	n.a.		
1947	76.1	n.a.		
1948	76.6	334		
1949	76.8	319		
1950	82.7	344		
1951	108.0	422		
1952	109.9	426		
1953	107.0	413		
1954	99.2	385		
1955	95.3	370		
1956	96.3	371		
1957	101.2	380		
1958	100.2	376	n.a.	
1959	97.1	372	100.0	
1960	97.1		99.8	
1961	96.9		99.6	
1962	97.0		99.7	
1963	100.0		102.8	
1964	99.6		102.4	
1965	99.5		102.3	

Table 12.--continued.

Year	Consumer Price Indices[1]	Cost of Living Indices of Clerical Grades[2]	Retail Price Indices[3]	Consumer Price Indices[4]
1966	100.9		103.7	n.a.
1967	105.1		108.0	100.0
1968	104.8		108.2	99.8
1969	104.4		107.1	99.4
1970	106.4		108.6	101.3
1971	108.1		110.2	102.9
1972	111.6			106.2
1973	(123.4)[b]			117.4
1974	(144.8)			137.8
1975	(151.3)			144.0

Sources:

1. International Monetary Fund, International Financial Statistics (Washington, D.C., various issues).

2. Department of Statistics, Monthly Statistical Bulletin of West Malaysia (Kuala Lumpur, February 1960).

3. Department of Statistics, Monthly Statistical Bulletin of West Malaysia (Kuala Lumpur, January 1973).

4. Department of Statistics, Monthly Statistical Bulletin of West Malaysia (Kuala Lumpur, September 1976).

There are a number of price indices that could be used as a deflator. Unfortunately, most of them are not complete. The most complete index available and the one that will be used as a deflator in this study is the Consumer Price Index (CPI) prepared by the International Monetary Fund. Even then it only runs from 1947-72 (see Table 12). The 1973 figure can be estimated by making use of the other set of Consumer Price Index (1967-75) prepared by the Malaysian Department of Statistics. The CPI for 1973 then works out to be 123.4.[48]

The pre-War figures are more difficult to estimate. The only available index that can provide some indication of the pre-War cost-of-living is the Cost of Living Index of Clerical Grades of Workers. This index (1939=100) revealed that the cost-of-living for clerks in 1948 was 3.34 times higher than it was in 1939. If it can be assumed that there was stability in the pre-War cost-of-living as well, the CPI for the pre-War period can also be estimated using the same procedure as before. The CPI for the pre-War period was estimated to be 22.9.[49] This assumes, of course, that it can be generalized to all consumers and not just clerks.

Rates of Return to Rubber Research

An investment can be generally defined as anything which involves an initial sacrifice followed by subsequent benefits. From

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[48] $CPI_{1973} = 117.4 \left(\frac{105.1}{100}\right) = 123.4$

[49] $CPI_{Pre\text{-}War} = \frac{76.6}{3.34} = 22.9$

this very general definition of investments, the two central problems of the theory of investment appraisal clearly emerge. The costs and benefits of an investment occur at different points of time. The first problem, then, is to decide how to compare costs and benefits which occur at different points in time, often referred to as the time value problem.

The second central problem arises out of the fact that the benefits of an investment, and at least some of the costs, occur in the future, which can never be known with certainty. The problem is then to decide how to take this element of uncertainty into account in the appraisal.

Any particular investment decision will inevitably be complex, with problems arising out of its own special situation, as well as with problems which it shares with investments in general. It is important to stress that any suggested procedure for taking optimal investment decisions is always based, implicitly or explicitly, on some model of the problem. Greater insight into the meaning and limitations of a procedure is often gained by describing the model on which it is based. Once this is accomplished the next step is to devise techniques and procedures to solve the problem of choice.

To assess the efficiency of investment on rubber research in Malaysia, as in any problem of public investment appraisal, three common decision rules or criteria that can be considered are (1) benefit-cost (B/C) ratio, (2) net present value (NPV), and (3) internal rate of return (IRR). The B/C ratio is merely the ratio of discounted benefits to discounted costs. Algebraically it can take one of two forms as shown by the formulae:

$$\frac{\sum_{t=1}^{n}\frac{GB}{(1+r)^t} - \sum_{t=1}^{n}\frac{OC}{(1+r)^t}}{K} \quad \text{or} \quad \frac{\sum_{t=1}^{n}\frac{GB}{(1+r)^t}}{K + \sum_{t=1}^{n}\frac{OC}{(1+r)^t}}$$

The NPV is simply the difference between the discounted benefits and discounted costs. The formula for this is

$$\sum_{t=1}^{n}\frac{NB}{(1+r)^t}$$

The IRR is defined as that rate of interest which, when used to discount the money flows of an investment, reduces its NPV to zero. In algebraic terms this can be shown as

$$\sum_{t=1}^{n}\frac{NB}{(1+i)^t} = 0$$

where:

GB = gross benefit

NB = net benefit

K = capital cost

OC = operating cost

r = interest rate

i = solution rate

Investment criteria, whether based on NPV, IRR, or B/C ratio, are devised so as to enable a choice between alternative uses of investible funds. In an economy with a perfectly competitive capital market, where the existing rate of interest reflects the social rate of time preference and there is no capital rationing, a straight forward application of the NPV formula or the IRR formula will suffice for an investment criterion. However, if the rate of return on private investment is well above the social rate of time preference either (a) because of short period disequilibrium, or (b) because the interest rate in the market does not reflect the social rate of time preference, investment criteria become less simple, and controversies about the correct criterion arise.

The question inevitably emerges as to which criterion to use for the present study. One way out is to view project evaluation in two stages: (1) the feasibility test or test for the minimum floor of acceptance or rejection; (2) the economic efficiency test or test for maximizing the objective, e.g., contribution to GNP. For the feasibility test, the decision rules are to accept projects if the NPV is greater than zero or the IRR is greater than the cost of capital (with the market rate of interest generally assumed to be an index of such opportunity costs of capital) or the B/C ratio is greater than one. This test does not involve any problem of criteria because all three criteria will give the same decision. The problem arises with the second test which is in fact the crucial phase of project evaluation. Given the objective(s) the criterion that will ensure economic efficiency depends on the nature of alternatives, size, and limitations of budgetary and other constraints.

The crux of the problem, then, is to decide on the investment criterion to use. Each of the three investment criteria algorithm (B/C ratio, NPV, and IRR) is now briefly considered.[50]

In the early years of applied cost-benefit analysis, the B/C ratio was one of the most popular decision rules used. A number of difficulties with its use were, however, soon encountered. A major flaw was its sensitiveness to the classification of project effects as costs in the denominator rather than as negative benefits in the numerator, and vice versa. The B/C ratio rule will be affected depending on how the division of project effects is made since it will affect the magnitudes which are entered as denominator and as numerator. Another problem is that the ratio can give incorrect rankings when applied to mutually exclusive projects. Two or more investments are mutually exclusive when the decision to undertake one of them absolutely precludes undertaking the other(s). This may arise because of a limitation on resource availability or because of a limitation in the opportunity to use the output of the investment.

Where constraints on the resource available for investment are present, the NPV rule does not give the optimal combination of projects such that the total combined cost exhausts the budget. Instead, projects should be ranked by their benefit-cost ratios at the predetermined discount rate.[51] While the B/C ratios can be used as a

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[50]The discussion on the technical issues of cost-benefit analysis draws heavily from Ajit K. Dasgupta and D. W. Pearce, Cost Benefit Analysis: Theory and Practice (London: Macmillan, 1974), pp. 159-73.

[51]Ibid., p. 161.

rule to rank projects for single-period rationing, the presence of multi-period rationing and lumpy projects give rise to complex problems which are only effectively solved by the use of programming techniques.[52]

The B/C ratio and NPV rules require the use of some predetermined social discount rate to discount future benefits and costs. An alternative rule is to calculate the discount rate which would give the project a NPV of zero and then compare this "solution rate," i, with the predetermined social discount rate.

One small drawback with the IRR is that the solution rate cannot be computed quickly since the IRR is the solution to a polynominal equation. A corollary of the latter is the possibility of multiple solutions when net benefits fluctuate between positive and negative.

A more serious problem concerns the appraisal of two or more mutually exclusive projects. An underlying assumption of the internal rate of return criterion is that cash flows of a project are reinvested at a rate internal to the project, i.e., i. The net present value, on the other hand, implies reinvestment of funds at the market rate, r. In other words the reinvestment rate is at the heart of the controversy concerning the ranking of mutually exclusive projects.

Given the possibility of conflict, the choice of criterion can only be given by reference to the objective. If the objective is to maximize profitability the question is simply which criterion indicates the profit maximizing choice. The answer really stems from the

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[52] Ibid., p. 162.

rationalization of the discounting procedure, taking the market rate of interest as the factor which determines the time value of money. Since this is the rate at which money can actually be borrowed and lent it is the appropriate discount rate to use rather than a hypothetical "solution rate" or IRR.

The consensus appears to be in favor of the NPV rule for deciding upon projects. But even if the NPV rule is accepted, there is still the question of whether to rank investment streams by excess benefits over costs, by the ratio of benefits to costs, or by the ratio of excess benefits to costs.

To this point the discussion has largely centered around the technical issues of cost benefit analysis. Of at least equal importance is the need to ensure that the investment rules or criteria fit the politically chosen maximand.[53] It behooves economists, therefore, to elucidate the nature of the choices being made in order to generate debate on the impact of different investment criteria on different people. The choice of criteria cannot be made in a vacuum. It depends on public choices as to the relevant goal.

Although economics is about optimization, there is still controversy in the profession on the choice of investment criteria. R. McKean eschews B/C ratios. Instead he would advocate maximizing the difference between the present values and costs, i.e., the excess benefit method, by using the marginal internal rate of return in

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[53]The discussion on policy objectives is based in large part on class materials prepared by Dr. A. A. Schmid for his course on Public Program Analysis which the writer took in the Spring of 1972.

computing present values.[54] Eckstein, on the other hand, favors the B/C ratio and points out two critical questions that affect the choice:[55] (1) What are the budget constraints, and (2) Are net benefits reinvested?

On the first question concerning budget constraints, Schmid is of the opinion that the opportunity cost choice between market rate and marginal rate depends on why there is a budget constraint. If no budget constraint exists, there is no difference between ranking by B/C ratios and marginal IRR, for the market rate becomes the marginal IRR. However, if the constraint is used to adjust for inflated net return computations, then the market rate (or social rate) is appropriate, not the marginal IRR. The market rate can then be used with McKean's procedure. The results would be equivalent to using the B/C ratio (so long as capital cost is the only limiting factor).

The issue of reinvestment of net benefits is also controversial. McKean suggests a "modified" rate of return which assumes net receipts can be reinvested at the marginal IRR. In other words, the relevant IRR to McKean is the marginal project available while to Eckstein it is zero because he sees no possibility of reinvestment. Schmid advocates that reinvestment should be assumed but only at the market

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[54] R. McKean, Efficiency in Government through Systems Analysis (New York: John Wiley and Sons, 1958).

[55] O. Eckstein, "A Survey of the Theory of Public Expenditure Criteria," in Public Finances: Needs, Sources and Utilization, ed. James M. Buchanan (Princeton: Princeton University Press, 1961).

rate if there is capital rationing.[56] As long as the net receipts are reinvested at the market rate, the number of years does not affect the benefit-cost ratio. The ratio, in effect, assumes reinvestment at the same rate used to compute the ratio and makes projects of different durations comparable. The strict IRR ranking assumes reinvestment at the IRR of each project to accomplish the same comparability.

The public would want to reinvest net receipts if they will earn more than the market rate, which is the rate that adjusts consumption and savings. If there are public projects yielding better than the market rate, the public will want to tax itself for public investments rather than private consumption or investment. This would seem to imply that reinvestment and original investment are both less than optimal.

However, the constraint could mean that the public do not believe these estimates. They may, therefore, neither want more original investment than the constrained budget nor reinvestment of net receipts. In that event, the agency concerned should not regard its nominal marginal rate of return as the reinvestment rate. Reinvestment should be considered but only at the market rate.

If the market rate of return is the relevant marginal rate, McKean's procedure reduces to a simple NPV calculation at the market

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[56]This is in line with Mishan's three conditions or "normalization procedure," viz. (1) that the reinvestment opportunities open to each of the benefits be made explicit and be utilized, (2) that a common outlay, and (3) a common investment period be established for all the investment streams under comparison to ensure a unique ranking of the alternative investment streams in question--see E. J. Mishan, Cost-Benefit Analysis (New York: Praeger, 1971).

rate, which is what the B/C ratio computed at the same rate amounts to. The former is an absolute figure of net present value while the latter is the ratio of discounted benefits to discounted costs. When project costs differ the ratio ranking is a convenient way of selecting projects with the greatest NPV for a given budget.

Although the consensus appears to be with the NPV rule as the correct one for optimal decision making, this seems to be based largely on technical considerations. In the final analysis, policy makers will have to decide what costs are limiting and whose reinvestment opportunities are relevant.

While it may appear in view of the importance of rubber to the economy that, historically, the rubber research budget was not limiting, there is evidently a constraint on the national budget in the sense that there are opportunity costs involved with the use of funds for rubber research. As such, the choice of what criterion to use is required of Malaysian policy makers.

There is no presumption as to what the policy objectives might be. Since it is possible to select criteria to fit a desired objective it was thought appropriate to present all three investment criteria here. This will provide policy makers a choice of investment criteria consistent with their policy objectives.

Analysis of Breeding and Associated Expenditures

In this section, an attempt is made to develop a set of rubber breeding and associated expenditures in Malaysia over fifty-five years, from 1918-73. The year 1918 was chosen as the starting point because this marked the beginning of systematic work on rubber improvement in

Malaysia. As already mentioned, this work was first carried out at the private research station of the RGA and, since 1921, at Prang Besar Estate. Table 13 shows the estimated expenditures of the private sector stations in current dollars. Prang Besar is the major private sector research station that has an uninterrupted record (except for the period 1942-45 when the Japanese occupied the country) of rubber research in Malaysia. Its contribution to breeding and selection work, relative to its expenditures is outstanding. PB 86, an early Prang Besar clone, ranked first out of 25 major clones in terms of the acreage planted as of 1969. It was still in second place to RRIM 600 as of 1973.[57]

The pattern of expenditures at the RRIM, following its establishment in 1925, is contained in Table 13. Apart from the direct costs of breeding and selection which in recent years constituted about one-third of total Plant Science Division expenditures and only some 5 percent of total RRIM expenditures (see Table 14), other research and development costs that are relevant to the breeding and selection work include:

a. complementary costs connected with work on crop exploitation or tapping and stimulation, soil investigations, pest and disease control, plant propagation, extension services, etc.,
b. indirect costs of using experimental station facilities, buildings and equipment, library, administration, staff training, etc.,

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[57] G. C. Iyer and T. Y. Pee, "Impact of Changes in Clonal Composition on Productivity," paper presented for the Rubber Research Institute of Malaysia 1977 Planters' Conference, Kuala Lumpur.

Table 13.--Rubber Research, Replanting and Associated Costs in Thousands of Current Malaysian Dollars.

Year	RRIM	Other Research Stations	Replanting[a]	Additional Fertilizers[b]	Total Costs
1918		68.0			68.0
1919		68.0			68.0
1920		68.0			68.0
1921		88.0			88.0
1922		93.0			93.0
1923		93.0			93.0
1924		93.0			93.0
1925	3.4	93.0			96.4
1926	50.6	93.0			143.6
1927	249.4	60.0			309.4
1928	352.9	60.0			412.9
1929	403.5	60.0			463.5
1930	454.0	60.0			514.0
1931	471.7	60.0			531.7
1932	453.9	75.0			528.9
1933	367.9	75.0			442.9
1934	378.5	75.0			453.5
1935	363.9	75.0		88.4	527.3
1936	494.7	75.0		123.0	692.7
1937	598.4	90.0		139.2	827.6
1938	688.3	90.0		169.4	947.7
1939	677.6	90.0		199.2	966.8
1940	773.8	90.0		199.2[c]	1,063.0
1941	792.6	90.0		199.2[c]	1,081.8
1942-45	342.6	90.0		--	432.6
1946	929.1	90.0		1,043.5	2,062.6
1947	1,248.4	105.0		1,179.6	2,533.0
1948	1,820.2	105.0		1,241.2	3,166.4
1949	2,144.0	120.0		1,406.8	3,670.8
1950	2,292.9	120.0		1,419.8	3,832.7
1951	2,801.7	120.0		1,342.4	4,264.1
1952	3,331.0	135.0	39,154.0	1,559.9	44,179.9
1953	3,582.2	135.0	57,737.4	1,433.0	62,887.6
1954	3,326.7	135.0	58,976.2	1,576.4	64,014.3
1955	3,505.9	150.0	64,218.0	1,763.1	69,637.0
1956	4,044.3	150.0	61,113.4	1,943.4	67,251.1
1957	4,488.4	150.0	62,333.2	2,345.4	69,317.0
1958	5,554.3	180.0	64,320.3	2,061.6	72,116.2
1959	5,894,3	180.0	67,512.8	1,943.8	75,530.9
1960	6,924.8	195.0	69,090.4	2,064.7	78,274.9
1961	7,378.3	195.0	71,235.7	2,188.2	80,997.2
1962	8,181.4	210.0	72,058.7	2,347.8	82,797.9

Table 13.--continued.

Year	RRIM	Other Research Stations	Replanting[a]	Additional Fertilizers[b]	Total Costs
1963	9,092.9	210.0	75,903.7	2,768.2	87,974.8
1964	10,028.6	225.0	79,756.4	3,456.8	93,466.8
1965	10,732.5	225.0	84,528.2	3,870.6	99,356.3
1966	12,337.4	255.0	90,748.0	4,536.0	107,876.4
1967	12,496.4	300.0	93,072.7	5,133.6	111,022.7
1968	12,801.2	240.0	104,298.5	6,513.3	123,853.0
1969	13,466.1	270.0	118,993.8	7,472.5	140.202.4
1970	14,476.8	270.0	120,610.7	7,874.0	143,231.5
1971	14,716.1	270.0	126,037.4	8,611.4	149,634.9
1972	16,325.0	240.0	124,818.1	9,017.4	150,400.5
1973	18,637.7	270.0	145,355.4	10,059.0	174,322.1

[a]Replanting cost was based on the Schedule IV (replanting cess) of 4.5 cents per pound of rubber produced.

[b]For mature area only.

[c]Additional fertilizer costs for 1940-41 were assumed to be the same as for 1939.

Sources: RRIM Expenditures: As in Table 5.
Other Stations: As in Table 6.

Table 14.--Cost of the RRIM Breeding and Selection Program as a Percentage of Total Plant Science Division and RRIM Expenditures.

Year	Breeding and Selection	Percentage of Total Expenditures Plant Sc. Div.	RRIM
1926	1,836	40	3.6
1927	12,670	40	5.1
1928	28,746	40	8.1
1929	27,210	40	6.7
1930	24,108	40	5.3
1931	23,477	40	5.0
1932	23,541	40	5.2
1933	19,818	40	5.4
1934	21,789	40	5.8
1935	20,303	40	5.6
1936	26,519	40	5.4
1937	28,965	40	4.8
1938	35,825	40	5.2
1939	32,572	40	4.8
1940	41,506	40	5.4
1941	39,214	40	4.9
1946	26,286	38.5	2.8
1947	42,651	38.5	3.4
1948	65,165	38.5	3.6
1949	68,813	38.5	3.2
1950	68,624	38.5	3.0
1951	81,253	38.5	2.9
1952	96,015	38.5	2.9
1953	105,119	38.5	2.9
1954	108,784	38.5	3.3
1955	110,545	38.5	3.2
1956	128,200	38.5	3.2
1957	140,846	38.5	3.1

Table 14.--continued.

Year	Breeding and Selection	Percentage of Total Expenditures Plant Sc. Div.	RRIM
1958	218,956	38.5	3.9
1959	224,696	38.5	3.8
1960	258,371	38.5	3.7
1961	266,971	38.5	3.6
1962	287,682	38.5	3.5
1963	320,638	38.5	3.5
1964	353,249	38.5	3.5
1965	337,258	35.7	3.1
1966	393,482	36.1	3.2
1967	339,040	30.6	2.7
1968	338,902	31.0	2.6
1969	380,328	31.4	2.8
1970	419,273	30.2	2.9
1971	407,368	30.4	2.8
1972	403,282	28.7	2.5
1973	414,350	27.0	2.2

Source: Rubber Research Institute of Malaysia, Applied Economics and Statistics Division (1977).

c. non-biological costs associated with research on the product, i.e., the expenditures of the chemical divisions are included since rubber has conventionally been exported in the form of ribbed smoked sheets (R.S.S.) and the price of the export product includes the costs of processing and chemicals added.

It will become evident from the above that the expenditures included as relevant to the breeding and selection work run the gamut of the RRIM's entire research program. If costs were limited to RRIM expenditures on breeding and selection an exceedingly conservative estimate of costs would have been made which is not realistic for this analysis. An important cost item that is not included either with the private sector or RRIM research expenditures is replanting cost. The measures called for in this massive undertaking, according to the Controller, Tan Sri Dr B. C. Sekhar, amounted to well over U.S. $500 million in the last twenty years alone.[58] Without this timely replanting program which accelerated the pace of replacement of the old unselected materials, the Malaysian rubber industry would not be as efficient as it is today. There must be a cost associated with the rapid increase in the yield of high yielding materials. This is mainly the cost of the replanting program and the associated cost of using high yielding materials in replanting.

Taking, first, the cost of the replanting program computations were simplified by assuming the annual cost spent on replanting from 1952 to correspond to the Schedule IV or replanting cess of 4.5 cents

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[58]B.C. Sekhar, "Scientific and Technological Developments in the NR Industry," Malaysian Rubber Review 1 (July 1976):26.

per pound collected each year. For the twenty-one year period, 1952-73, the total replanting cess collected and assumed to be expended on replanting was estimated to exceed U.S. $700 million. Compared to the Controller's 1976 estimate of over U.S. $500 million spent on replanting in the last twenty years, the present figure may seem high. However, the Controller's figure probably refers only to the direct cost of the replanting program. The cost of administering the program particularly that on smallholdings can be heavy. Thus it was mentioned that, initially, "it took $1 million to give away some $3.5 million . . ." but in time "only $1.25 million was needed to give away about $8 million."[59] In other words, the administrative cost of the smallholder replanting program was at least 20 percent of total cost. If it is assumed that 15 percent of the replanting cost is for administration, then the figure of U.S. $700 million seems reasonable.

Another cost to be added is the cost of applying extra fertilizers to the high yielding materials. Estimation of fertilizer cost is difficult because no published data are available on the type and quantity of fertilizers used by the rubber industry before 1968. Fortunately, however, historical prices of fertilizers (ammonia sulphate, Christmas Island Rock Phosphate (CIRP), and muriate of potash) were kept by the main fertilizer manufacturer in the country.[60] To obtain annual prices a colleague from the Soils and Crop Management Division suggested weighting the prices for ammonia sulphate, CIRP,

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[59]K. S. Kwan, "The Smallholders' Replanting Scheme," Ekonomi (Kuala Lumpur) 1 (1960):83.

[60]Imperial Chemical Industries (Malaysia).

and muriate of potash, respectively, in the following proportions: 50:25:25. The resulting weighted average prices of fertilizers are contained in the last column of Appendix D. It is interesting to observe that the prices obtained by this relatively crude procedure are quite close to the average annual prices of fertilizers given by the Department of Statistics from 1968 onwards.

To replenish the higher drainage loss in nutrients from high yielding trees more fertilizers are required than for unselected seedling trees. A conservative estimate is that high yielding trees should receive at least 25 percent more fertilizers than for trees of unselected material.[61] From figures provided by the Department of Statistics, it was worked out that the average consumption of fertilizers on estates in 1973 was just over 1 pound per tree. This was also the amount used on estates managed by the largest agency house in the country.[62]

In this study we assume that each mature high yielding tree would require 1.25 pounds of fertilizer, as compared to 1 pound per unselected seedling tree. In other words, another 0.25 pound of fertilizer would have to be added to each mature high yielding tree. This is probably an overestimate since the rate on estates (which have more than 90 percent of their planted area under high yielding trees) in 1973 is only 1 pound per tree per year. Moreover, it is a well known fact that little or no fertilizers are used on many of the smaller holdings.

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[61] N. K. Soong, Private communications, 1977.

[62] R. Shepherd, Private communications, 1977.

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A third cost item that was added to total research expenditures is the additional cost of using high yielding materials, primarily budded clones. The main cost items are for clonal seeds, budding material and labor. The commercial rate for clonal seeds in 1973 was about 22 cents per seed, while budding cost (inclusive of material and labor) is 15 cents per successful point.[63] In estimating the additional cost of using high yielding materials, the initial planting density on estates and smallholdings was taken to be 180 trees and 240 trees per acre, respectively.

An alternative set of expenditure figures was worked out for the "without" situation, i.e., if high yielding materials were not available. In this situation, the cost of the replanting program was excluded from the expenditure estimates. This is because replanting costs would differ little between using high yielding or unselected materials.

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[63] P. H. Tan, Private communications, 1977.

CHAPTER V

QUANTITATIVE FINDINGS

The empirical results are presented in two parts. The first part details the primary direct benefits from rubber research, while the second part documents in an indirect way the extent of secondary benefits that might have been generated as a result of investment in rubber research.

Direct Primary Benefits

The direct benefits are discussed separately under: (1) estimates of the total gains from a technologically induced shift in the supply curve for rubber, together with estimates of the distribution of these gains between producers and consumers; (2) estimates of the distribution of producer benefits between estates and smallholdings; and (3) estimates of the distribution of producer benefits between different factors of production. The estimates of the economic worth or efficiency of the investment on rubber research are then discussed.

Computations were made assuming different elasticities of supply ($e_E = 0$, $e_S = 0.25$; $e_E = 0$, $e_S = 0.5$) and demand ($n = -0.5$, -1.0, -2.0), and different rubber prices received by the two producing subsectors (P_E = RSS 1; P_S = RSS 3). Only the results based on supply elasticities of $e_E = 0$, $e_S = 0.25$, and demand elasticities of $n = -1.0$, -2.0 are discussed here. The other results are given in Appendix E.

Distribution of Research Benefits between Consumers and Producers

The average value of gross social benefits (1932-73) and the relative distribution of these benefits are shown in Tables 15 and 16. The gross social benefits after 1973 are assumed to be the same as the 1973 figures. (For details on how the assumptions were made, see section on Rates of Return to Investment on Rubber Research). The results support earlier findings that a relatively high price elasticity of demand will favor the producers, while consumers will tend to benefit if the price elasticity of demand is low.[1] De Castro and Schuh (1977) have further indicated that it is the relative magnitude of the elasticities that is important.[2] If the supply elasticity were larger than the demand elasticity, regardless of the absolute size of the demand elasticity, the consumer would tend to receive a larger share of the benefits. The implication is that with the relatively low elasticities of supply, rubber producers should get proportionately more of the benefits. The results, generally, show that it is only when the price elasticity of demand exceeds -1.0 (which is the computed lower range for Malaysian rubber) that the share received by producers can exceed that received by consumers. At a demand elasticity of -2.0, producers will evidently receive the bigger share (see Table 16).

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[1]Hertford and Schmitz, "Measuring Economic Returns to Agricultural Research," p. 153.

[2]J. P. Ramalho de Castro and G. Edward Schuh, "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study," in Resource Allocation and Productivity in National and International Research, eds. Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (Minneapolis: University of Minnesota Press, 1977, p. 508).

Table 15.--Estimates of Social Benefits from Rubber Research (When n = -1.0; e_E = 0, e_S = 0.25) in Thousands of 1963 Dollars.

Year	Producer's Gain			Consumer's Gain			Total Social Benefits		
	Estates	Smallholdings	Total	Estates	Smallholdings	Total	Estates	Smallholdings	Total
1932	0.3	0.0	0.3	216.4	0.0	216.4	216.7	0.0	216.7
1933	2.3	0.0	2.3	742.8	0.0	742.8	745.1	0.0	745.1
1934	9.1	0.0	9.1	2,138.3	0.0	2,138.3	2,147.4	0.0	2,147.4
1935	33.0	10.6	43.6	3,939.6	42.3	3,981.9	3,972.6	52.9	4,025.5
1936	99.2	37.1	136.3	7,725.5	148.0	7,873.5	7,824.7	185.1	8,009.8
1937	96.7	37.4	134.0	9,675.5	149.3	9,824.8	9,772.1	186.7	9,958.8
1938	260.8	97.0	357.9	12,105.5	384.8	12,490.2	12,366.3	481.8	12,848.1
1939	912.7	186.9	1,099.6	25,457.8	738.8	26,196.7	26,370.5	925.8	27,296.3
1940	335.0	110.7	445.7	20,028.8	441.3	20,470.2	20,363.8	552,0	20,915.8
1941	344.1	114.0	458.1	20,573.1	454.6	21,027.7	20,917.1	568.6	21,485.8
1946	2,500.4	722.7	3,233.1	56,055.1	2,837.6	58,892.6	58,555.4	3,560.3	62,115.7
1947	752.4	113.7	866.2	16,868.1	451.4	17,319.4	17,620.5	565.1	18,185.6
1948	1,326.0	179.4	1,505.4	25,007.4	710.2	25,517.5	26,333.3	889.6	27,222.9
1949	2,366.2	278.6	2,644.9	31,299.5	1,092.6	32,392.1	33,665.7	1,371.3	35,037.0
1950	8,955.9	372.6	9,328.5	94,835.5	1,478.3	96,313.8	103,791.4	1,850.9	105,642.3
1951	19,989.4	1,489.7	21,479.2	141,830.3	5,772.1	147,602.4	161,819.7	7,261.9	169,081.6
1952	13,630.6	1,108.9	14,739.5	80,755.4	4,229.0	92,984.4	102,386.0	5,337.9	107,723.9
1953	10,566.1	845.8	11,411.9	66,130.7	3,211.8	69,342.6	76,696.8	4,057.6	80,755.4
1954	11,228.8	1,038.5	12,267.3	70,936.9	3,933.7	74,870.6	82,165.7	4,972.3	87,137.9
1955	22,593.0	1,467.2	24,060.2	134,474.3	5,647.0	140,121.4	157,067.2	7,114.2	164,181.5
1956	23,411.7	1,421.5	24,833.2	124,556.6	5,420.2	129.976.8	147,968.3	6,841.7	154,810.0
1957	26,826.5	1,445.8	28,272.3	125,860.0	5,465.5	131,325.4	152,686.4	6,911.3	159,597.7
1958	30,000.8	1,562.4	31,563.2	129,698.5	5,831.5	135,529.9	159,699.2	7,393.9	167,093.1
1959	47,967.6	2,573.9	50,541.5	189,739.9	9,528.2	199,268.1	237,707.5	12,102.1	249,809.6
1960	61,329.4	3,696.6	65,026.0	220,952.7	13,398.4	234,351.1	282,282.0	17,095.0	299,377.1
1961	61,425.7	3,948.4	65,374.0	194,647.3	13,904.4	208,551.7	256,073.1	17,852.7	273,925.8
1962	74,340.3	5,163.4	79,503.7	205,467.9	17,408.8	222,876.7	279,808.2	22,572.2	302,380.4
1963	82,980.1	6,857.0	89,837.1	206,958.8	21,979.6	228,938.4	289,938.9	28,836.7	318,775.6
1964	99,665.3	9,205.3	108,870.6	220,056.9	28,022.0	248,078.9	319,722.2	37,227.3	356,949.5
1965	126,727.7	13,088.4	139,816.2	249,936.9	37,937.0	287,873.9	376,664.7	51,025.5	427,690.2
1966	155,025.8	17,777.7	172,803.5	262,651.7	48,024.6	310,676.3	417,677.6	65,802.4	483,479.9
1967	153,567.5	22,062.8	175,630.2	228,309.4	52,328.9	280,638.2	381,876.7	74,391.6	456,268.4
1968	173,694.1	27,610.2	201,304.2	246,564.1	64,431.5	310,995.5	420,257.9	92,041.6	512,299.5
1969	318,367.4	31,751.9	350,119.3	372,932.2	82,901.4	455,833.6	691,299.7	114,653.2	805,952.9
1970	288,760.3	58,732.8	347,493.1	313,669.9	114,616.5	428,286.4	602,430.4	173,349.3	775,779.7
1971	267,625.3	91,775.8	359,401.1	273,918.8	132,820.6	406,739.4	541,544.0	224,596.5	766,140.5
1972	254,667.3	139,467.9	394,135.2	247,732.4	154,803.5	402,535.9	502,339.7	294,271.4	796,671.2
1973	464,768.6	63,706.2	528,474.8	415,616.4	140,300.7	555,917.1	880,385.4	204,006.8	1,084,392.0

Assumptions: Prices Received by Estates are based on RSS 1
Prices Received by Smallholdings are based on RSS 3

Table 16.--Estimates of Social Benefits from Rubber Research (When n = -2.0; $e_E = 0$, $e_S = 0.50$) in Thousands of 1963 Dollars.

Year	Producer's Gain			Consumer's Gain			Total Social Benefits		
	Estates	Smallholdings	Total	Estates	Smallholdings	Total	Estates	Smallholdings	Total
1932	108.4	0.0	108.4	108.2	0.0	108.2	216.6	0.0	216.6
1933	373.1	0.0	373.1	371.4	0.0	371.4	744.5	0.0	744.5
1934	1,076.0	0.0	1,076.0	1,069.1	0.0	1,069.1	2,145.1	0.0	2,145.1
1935	1,994.6	29.4	2,023.9	1,969.8	23.5	1,993.3	3,964.4	52.9	4,017.2
1936	3,937.1	102.9	4,040.0	3,862.8	82.2	3,945.0	7,799.9	185.1	7,985.0
1937	4,910.2	103.7	5,014.0	4,837.7	83.0	4,920.7	9,748.0	186.7	9,934.7
1938	6,248.4	267.9	6,516.2	6,052.7	213.8	6,266.5	12,301.1	481.6	12,782.7
1939	13,413.4	514.9	13,928.3	12,728.9	410.4	13,139.3	26,142.3	925.3	27,067.6
1940	10,265.7	306.8	10,572.4	10,014.4	245.2	10,259.6	20,280.1	551.9	20,832.0
1941	10,544.6	316.0	10,860.6	10,286.5	252.5	10,539.1	20,831.1	568.5	21,399.7
1946	29,902.8	1,918.2	31,884.1	28,027.5	1,576.1	29,603.6	57,930.4	3,557.3	61,487.7
1947	8,998.4	314.2	9,312.5	8,434.0	250.7	8,684.8	17,432.4	564.9	17,997.3
1948	13,498.2	494.7	13,992.8	12,503.7	394.5	12,898.2	26,001.8	898.2	26,891.0
1949	17,424.4	763.2	18,187.6	15,649.8	606.9	16,256.6	33,074.2	1,370.1	34,444.2
1950	54,134.7	1,029.1	55,163.7	47,417.8	821.2	48,239.0	101,552.5	1,850.3	103,402.7
1951	85,907.2	4,045.9	89,953.1	70,915.1	3,205.6	74,120.7	156,822.4	7,251.5	164,073.9
1952	54,600.7	2,978.3	57,578.9	44,377.7	2,348.1	46,725.9	98,978.4	5,326.4	104,304.9
1953	40,989.9	2,264.8	43,254.7	33,065.4	1,783.3	34,848.7	74,055.3	4,048.1	78,103.4
1954	43,890.0	2,776.0	46,666.0	35,468.5	2,184.0	37,652.5	79,358.5	4,960.0	84,318.5
1955	84,181.9	3,966.0	88,148.0	67,237.1	3,135.9	70,373.0	151,419.1	7,101.9	158,521.1
1956	79,837.1	3,817.3	83,654.4	62,278.3	3,009.6	65,287.9	142,115.4	6,826.9	148,942.3
1957	83,049.9	3,859.2	86,909.1	62,930.0	3,034.4	65,964.4	145,979.9	6,893.6	152,873.6
1958	87,349.8	4,133.5	91,483.4	64,849.2	3,237.1	68,086.4	152,199.1	7,370.7	159,569.7
1959	130,845.7	6,770.7	137,616.4	94,869.9	5,288.7	100,158.6	225,715.6	12,059.4	237,775.0
1960	156,473.4	9,582.9	166,056.4	110,476.3	7,435.0	117,911.3	266,949.7	17,017.9	283,967.6
1961	143,392.9	10,034.8	153,427.7	97,323.6	7,713.0	105,036.6	240,716.6	17,747.8	258,464.4
1962	158,489.2	12,740.4	171,229.6	102,733.9	9,651.5	112,385.4	261,223.2	22,391.9	283,615.2
1963	165,714.5	16,356.7	182,071.2	103,479.4	12,177.3	115,656.7	269,193.9	28,534.0	297,727.8
1964	184,777.4	21,225.0	206,002.4	110,028.4	15,513.5	125,541.9	294,805.9	36,738.5	331,544.3
1965	220,014.2	29,237.4	249,251.6	124,968.4	20,987.1	145,955.6	344,982.6	50,224.5	395,207.1
1966	247,595.2	37,981.9	285,577.2	131,325.9	26,537.9	157,863.7	378,921.1	64,519.8	443,440.8
1967	229,330.3	43,546.1	272,876.4	114,154.7	28,849.9	143,004.6	343,484.9	72,395.9	415,880.9
1968	253,552.6	53,974.3	307,526.9	123,282.0	35,511.2	158,793.2	376,834.7	89,485.6	466,320.2
1969	425,241.7	66,418.9	491,660.6	186,466.1	45,784.1	232,250.2	611,707.8	112,202.9	723,910.7
1970	373,405.2	103,732.0	477,137.2	156,834.9	62,933.2	219,768.1	530,240.2	166,665.1	696,905.4
1971	337,678.4	[illegible]	476,916.1	136,959.4	72,343.0	209,302.4	474,637.7	211,580.8	686,218.6
1972	314,866.7	188,364.9	503,231.6	123,866.2	83,513.9	207,380.1	438,732.9	271,878.6	710,611.6
1973	556,384.7	120,406.6	676,791.2	207,808.2	77,237.9	285,046.1	764,193.1	197,644.4	961,837.5

Assumptions: Prices Received by Estates are based on RSS 1
Prices Received by Smallholdings are based on RSS 3

The observed difference between the results obtained in this study (which were based on formulae developed by Hertford and Schmitz) and de Castro and Schuh's is apparently due to differences in formulations used. This was recently demonstrated by Scobie.[3] He was able to show that the formulae presented by Hertford and Schmitz, and de Castro and Schuh, among others, do not necessarily give the same answer when the question is posed: Under what conditions will consumers gain more than producers as a result of a technological change in production?

Of related interest is the extent of research benefits received by consumer countries. The main users of Malaysian rubber are the U.S., with its huge automobile industry, the U.K. and other West European countries, and the Soviet Union. The inference is that they are the main beneficiaries of consumer benefits generated by rubber research undertaken by Malaysia.

Distribution of Research Benefits between Estates and Smallholdings

Tables 15 and 16 depict how producer benefits are distributed between the two producing subsectors. It can be readily seen that the estate subsector has been the main beneficiary of rubber research work undertaken. Although this is in line with conventional wisdom that estates have received the greater share of research benefits, it is still surprising to note how lopsided the distribution of producer benefits has been.

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[3]Grant M. Scobie, "Who Benefits from Agricultural Research?" Review of Marketing and Agricultural Economics 44 (December 1976): 198-201.

Two main factors appear to be responsible for the disproportionately large gains received by the estate sector: (a) the higher average yields on estates, and (b) the higher percentage of the estate area under high yielding materials. Both of these features are reflected by the shift factor, k. Indeed, Table 11 shows that over the period under study, the estate shift factor was always larger than the smallholding figure.

Another inference that can be drawn from the importance of the magnitude of the shift factor is that the distribution of producer benefits within each subsector is unlikely to be even, given the structure of the two producing subsectors (see Tables 1 and 2). The main beneficiaries, then, are likely to be the bigger estates, which are generally foreign-owned, and the bigger smallholdings.

Distribution of Research Benefits between Factors of Production

The benefits received by the producer will be divided among the factors of production in inverse proportion to the elasticity of supply.[4] If the supply of land is relatively inelastic, then land owners would receive a proportionately large share of the producer benefits in the form of an increased rent to land. If the supply of labor is relatively inelastic, then, the rubber workers would receive a greater proportion of producer gains in the form of increased wages.

Although no statistical estimate of the elasticities of supply of land and labor to the rubber sector is available, the high

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[4]Harry Ayer, "The Costs, Returns and Effects of Agricultural Research in a Developing Country: The Case of Cotton Seed Research in Sao Paulo, Brazil" (Ph.D. dissertation, Purdue University, 1970), p. 166.

unemployment and underemployment rates in the rural areas suggest that the supply of labor is highly elastic, and the fact that land is a state matter implies that for all practical purposes land for rubber production is inelastic in supply.[5] Land values for rubber land have increased markedly during the post-War period, rising several times in some cases, depending on such factors as location, size of parcel, clones planted, age of trees, soil, terrain, etc.[6] Although wages of rubber estate workers have improved due, in the main, to the efforts of the NUPW, the increase has been relatively small in comparison to that of land values. Table 17 shows that even for tappers on rubber estates, who constitute the bulk of estate workers and are generally better paid, the increase in earnings has been relatively modest. In practice, wages do not adequately reflect the real price of labor since estates provide various services and amenities such as free housing, water, power, medical attention, maternity benefits, etc. However, the relative order of increase in deflated earnings shown in the table may be a reasonable indicator of the improvement or lack of improvement in real wages. The meager evidence available on land values and wages suggest that land owners may have been the main beneficiary of producer benefits.

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[5] Third Malaysian Plan, 1976-1980 (Kuala Lumpur: Government Press, 1976), pp. 72-79.

[6] Although there are still extensive areas of the country that are suitable for rubber planting (see Pee and Ani Arope, 1976), virtually no new land has been alienated to the private sector for rubber cultivation after the War.

Table 17.--Average Monthly Earnings of Tappers on Estates.

Year	Current Earnings	Deflated Earnings
	(dollars per month)	
1956	78	81.0
1957	81	80.0
1958	n.a.	n.a.
1959	82	84.4
1960	94	96.8
1961	86	88.8
1962	86	88.7
1963	85	85.0
1964	91	91.4
1965	88	88.4
1966	94	93.2
1967	97	92.3
1968	99	94.5
1969	116	111.1
1970	n.a.	n.a.
1971	110	101.8
1972	107	95.9
1973	149	120.7

n.a. = not available

Source: Department of Statistics, Rubber Statistics Handbook (Kuala Lumpur, various issues).

Returns to Investment on Rubber Research

The foregoing benefit and cost streams are now brought together to estimate the efficiency of investing on rubber research.

Since the present stock of high yielding trees on the ground will continue to produce well into the future, the cost and benefit streams from rubber research were projected to 1990, more than seventy years after breeding and selection of high yielding materials was first started on an organized scale. In so doing every effort was made to be conservative in the estimation of the cost and benefit streams.

Although in this analysis the costs of the breeding and selection program and associated research expenditures were terminated in 1973, expenditures in connection with administration, extension, publication and information were continued into 1990, at the 1973 level. (In 1973 these expenditures were estimated to amount to about 30 percent of total RRIM expenditures for that year.) Likewise, replanting costs were continued at the 1973 level to 1990 using the present stock of modern high yielding materials. Research benefits were also assumed to continue at the 1973 level.

To enable comparison with earlier studies, the internal rates of return (IRR) from investment in rubber research, obtained for the likely values of the supply and demand elasticities, are shown in Table 18. The total (producer and consumer) returns exceed 24 percent and are comparable with those obtained in similar studies on other crops, mostly annuals.[7] These relatively high rates are particularly

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[7]Arndt and Ruttan, "Valuing Productivity of Agricultural Research," Table 1-1, p. 5.

Table 18.--Internal Rates of Return from Investment on Rubber Research Assuming Different Price Elasticities of Supply and Demand, 1918-1990 (Based on 1963 Dollars).

IRR (%)	(e_E, e_S) \ n	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	24.80	24.20	23.80	23.60
	(0,0.50)	24.80	24.20	23.80	23.60
Producer	(0,0.25)			11.60	18.80
	(0,0.25)		0.50	11.90	18.90

Assumptions: P_E = RSS 1; P_S = RSS 3.

significant when it is remembered that, unlike many of the earlier studies, the entire package of rubber research costs, plus the costs of the replanting scheme and the associated costs of using high yielding materials were included. The other measures of economic worth, NPV and B/C ratio, are displayed in Appendix F.

While the aggregate rates of return are of interest, from Malaysia's standpoint the rates of return to that portion of research benefits she can capture, i.e., producer benefits are more important. Table 19 reveals that even if the benefits included are limited to those received by producers, the IRRs were still positive and significant. The IRR was found to be about 12 percent assuming that the elasticity of demand for Malaysian rubber is not smaller than -1.0. In comparison the estimated social opportunity cost of capital is about 10 percent in Malaysia.[8] It should also be mentioned that

[8] S. C. Lim, "Land Development Schemes in West Malaysia," p. 171.

Table 19.--Internal Rates of Return from Investment on Rubber Research Assuming Different Price Elasticities of Supply and Demand when Yields of Unselected Materials are Adjusted, 1918-1990 (Based on 1963 Dollars).

IRR (%)	(e_E, e_S) \ n	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	23.00	22.50	22.30	22.10
	(0,0.50)	23.00	22.50	22.30	22.10
Producer	(0,0.25)			12.60	18.20
	(0,0.50)			12.80	18.20

Assumptions: P_E = RSS 1; P_S = RSS 3.

these figures represent only the returns that can be quantified. But even the measurable returns to rubber that she can capture are apparently high enough to justify Malaysia's heavy investment on rubber research.

Sensitivity Analyses

Mention was earlier made that there could be a downward bias in the estimated yields of unselected materials because of the post-War replanting scheme to replant with high yielding materials. To take note of this possibility, the rates of return were recomputed by using an adjusted yield series for the unselected materials. (The second set of figures was estimated by postulating that if high yielding materials were not available, and there had not been a government replanting scheme, planters would have to resort to unselected materials in replanting. Since the cost of replanting would differ little between unselected and high yielding materials, the replanting cost associated with high yielding materials should be deducted from the cost stream before making the recomputations.) The rates of return, 22-23 percent, were substantially similar to the earlier set of yield figures (see Table 19).

Another sensitivity test performed was to determine whether the rates of return would be affected if research costs and benefits were terminated, arbitrarily, in 1973. Again, the IRR values were substantially similar to the earlier results (Table 20).

Table 20.--Internal Rates of Return from Investment or Rubber Research Assuming Different Price Elasticities of Supply and Demand, 1918-1973 (Based on 1963 Dollars).

IRR (%)	(e_E, e_S) \ n	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	24.70	24.00	23.70	23.50
	(0,0.50)	24.70	24.00	23.70	23.50
Producer	(0,0.25)			7.60	18.30
	(0,0.50)			8.10	18.40

Assumptions: P_E = RSS 1; P_S = RSS 3.

A further indication that the figures on rates of return to rubber research investment are conservative is that no account was taken of revenue returned to the MRRDB by the RRIM. From 1946 to 1955 it was estimated that \$1.4 million were returned to the MRRDB "in the form of income realized by the sale of rubber and planting materials."[9]

[9]Planters Bulletin, No. 16 (1955), p. 3.

In part this was due to the dearth of annual income figures, especially during the early years. Additionally, it was felt that since the annual figures were likely to be relatively small, leaving them out should not affect the measures of economic worth markedly.

It has also frequently been asserted that the Malaysian cost-of-living index is one of the most stable in the world. If true this would imply that the rates of return would differ little, irrespective of whether deflated or historical figures were used in the computations. To test this assertion, current or historical figures were used to recompute the rates of return. Table 21 provides confirming evidence that there is only a small difference, of about 5 percent, between the IRRs using deflated and current values.

Table 21.--Internal Rates of Return from Investment on Rubber Research Assuming Different Price Elasticities of Supply and Demand, 1918-1990 (Based on Current Dollars).

IRR (%)	(e_E, e_S) \ n	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	30.00	29.30	28.90	28.70
	(0,0.50)	30.00	29.30	28.90	28.70
Producer	(0,0.25)			14.70	24.00
	(0,0.50)		1.70	15.00	24.00

Assumptions: P_E = RSS 1; P_S = RSS 3.

Secondary Benefits

In addition to the direct social benefits generated by rubber research, there may be indirect contributions termed secondary benefits or linkages.

The need for terms such as secondary benefits or linkages arose from the fact that conventional project appraisal, being strictly partial equilibrium, ignored many interdependencies and indirect effects on other parts of the economy. The inclusion of secondary benefits, thus, represents an attempt to move project appraisal towards a more systems-oriented approach of general equilibrium analysis.[10] Following Ward, the following categories of secondary benefits have been identified:[11]

1. Indirect benefits

   a. Induced-by benefits, as represented by an increase in incomes received by those indirectly supplying inputs to the rubber industry.

   b. Stemming-from benefits are earnings received by those involved in rubber-based industries which use rubber as an input in the production process.

   c. Household respending multipliers arising from the change in income indirectly resulting from the respending of income earned by income recipients in (a) and (b) above.

2. Externalities

   a. Economies of scale in some production process arising from increased demand created by the rubber industry

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[10]William A. Ward, "Employment Objectives and Agricultural Project Appraisal: A Review of Benefit-Cost Theory, with Research Recommendations for Improving Application," Draft Report prepared for the MSU African Rural Employment Project, 1974, p. 40.

[11]Ibid., pp. 41-42.

or from the increased availability of some factor whose supply is augmented by the industry.

b. Technological spillovers which affect the physical output that other producers can obtain from their physical inputs.

3. Dynamic secondary benefits which affect the shape and form of the aggregate production function. One such benefit is improved attitudes.

4. Intangibles, involving non-economic effects such as lives saved, reductions in human misery through, for example, disease eradication.

Indirect Benefits

With full employment and perfect competition, indirect benefits do not exist, since all factors are paid their marginal opportunity cost under these conditions, and no "higher" use exists for each of the resources. However, where less than full employment and/or imperfect competition prevails, indirect benefits can be generated by increasing the demand for these resources. Under these conditions, the increased demand for the resources will generate "rents" which form the heart of indirect analysis. For unemployed or underemployed resources, the rents are represented by the difference in real factor earnings with the industry over those without the industry. The quasi rents for unemployed or underemployed capital resources represent the indirect benefits. Since quasi rents include pure profits, indirect benefits flow directly from projects which stimulate production by imperfectly competitive firms.

To consider the extent of indirect benefits in the rubber industry, an input-output table of the Peninsular Malaysian economy can provide valuable insights into the interrelationship between the rubber industry and other sectors of the economy. A 1965 input-output table used by Radhakrishnan (1974), "indicates that in 1965 the rubber industry had only a few backward linked industries and the strength of these linkages was very weak. Moreover since imported inputs only account for about 1.4 percent of the industry's total gross outlays, the potential for the development of import substituting backward-linked industries is also very limited."[12] In other words, indirect benefits of the induced by variety are likely to be small. The main reason is that rubber production, as in the case of other plantation crops, is basically a simple process requiring relatively large inputs of labor but very few purchased intermediate inputs. As a result, the demand for purchased inputs and, hence, the inducements to invest in input-producing industries has been quite weak. The main purchased inputs used in rubber production: formic acid, fertilizers, fungicides, weedicides, tapping and collection equipment, processing equipment, etc. only amounted to about 6 percent of the total value of estate and smallholding output.[13]

The only forward linkage or stemming from benefits was in the manufacturing of rubber products. Although much publicity has been given to the building of a rubber-based industry in the country, what exists at present is still relatively small; the main products being rubber tires and tubes, rubber footwear, and foam rubber products. The production of wood chips and furniture from rubber wood is a new activity, and is still on a very small scale.

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[12]Radhakrishan, "Role of Rubber in West Malaysian Economy," p. 164.

[13]Ibid., p. 165.

Going now to the third type of indirect benefits, household induced income, it is normally presumed to cancel out under the traditional "with and without" project test.[14]

Externalities

Non-market externalities which result in the provision of free inputs to other industries can be created by the rubber industry either as a corollary of economies of scale or through technological spillovers. Externalities of the first type can be represented by the industry's demand for transportation services. The resulting transportation network, originally developed for the tin and rubber industries, created externalities by increasing the profitability (or reducing the costs) of establishing and operating other industries. In fact, the concentration of the transportation network along the western belt of the country was directly responsible for the rapid export-led growth of the western half of the country. The eastern part remains relatively underdeveloped to this day.

Dynamic Secondary Benefits

In the class of dynamic secondary benefits, mention can be made of the industry's role in promoting mass education. The provision of a school on all estates containing ten or more children of school going age was stipulated by the Labor Code of 1923. These schools were to be provided out of estate funds and, perhaps understandably, most managers were not too enthusiastic about the provision. Apart

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[14]Ward, "Employment Objectives and Agricultural Project Appraisal: Review of Benefit-Cost Theory," p. 52.

from the costs involved, they probably preferred a continued abundant supply of cheap, uneducated and subservient workers.[15] Thus most estates ratified the provisions by setting up poorly equipped vernacular (Tamil) schools teaching only up to the primary level. The lack of relevance in the curriculum, excessive regimentation and paternalism, it is alleged, resulted in the children of estate workers remaining as estate workers. Although conditions and opportunities have improved since the country's independence, it is perhaps fair to say that dynamic secondary benefits generated by the industry in the form of "improved attitudes," at least in the past, was small.

Intangibles

In the class of secondary benefits known as intangibles, however, the benefits conferred by the industry have been substantial. When rubber was first introduced at the turn of the century, mortality rates due to malaria, dysentry, beriberi, and hookworms were very high. The government was largely responsible for eradicating malaria in the urban areas. In the rural areas, however, much of the early eradication work was carried out by rubber estates. Health services on estates have also improved over the years and today most rubber estate workers receive better free medical care than most other rural dwellers. Every large estate has its own dispensary and hospital assistant, and larger estates may maintain centralized group hospitals. In this way, estates have not only saved lives, through eradication

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[15]Radhakrishan, "Role of Rubber in West Malaysian Economy," p. 192. This point was also made by Beckford (1969) in his critique of conditions in the "plantation economies."

of diseases, but have also reduced suffering and misery caused by sickness and poor health.

CHAPTER VI

SUMMARY AND POLICY IMPLICATIONS

Summary

The overall aim of this study is to add to the empirical evidence on returns from agricultural research in developing countries. The specific research objectives are: (1) to document the evolution of rubber research in Malaysia; (2) to test the consistency of the Malaysian experience in rubber and rubber research with the "induced development model"; (3) to estimate the social returns from investment on rubber research; (4) to evaluate the distribution of research benefits between the two producing subsectors and between different factors of production; and (5) to assess the extent of secondary benefits generated by the rubber industry.

Malaysia has been a leader in rubber research ever since the first "plantation" or estate was started about 1896. In the early days, before the first World War, research was conducted under the auspices of government by the Singapore Botanic Gardens and the Department of Agriculture, and cooperatively by the industry through private research stations.

Research during this period was largely *ad hoc* and uncoordinated. Much of the initiative and advance in tree improvement in this period was made by the private sector, chiefly at the RGA Station and Prang Besar Estate.

Organized or centralized rubber research began with the establishment of the RRIM in 1925; at which time most private stations including the RGA Station, were closed down. Prang Besar Research Station, belonging to Harrisons and Crosfield, the biggest agency house in the country, was the major exception.

Official rubber research was financed by a research cess levied on every pound of rubber produced and exported from the country. This cess, in recent years, has constituted about 0.3 percent of the country's GDP. Compared to the fact that developed and developing countries, on average, spend about 2 percent and 0.2 percent of their GNP, respectively, on all types of research, it appears that Malaysia's massive deployment of resources for rubber research is unparalleled by any other developing country. Further, it was estimated that Malaysia alone has been responsible for about 85 percent of all research on natural rubber.

The historical evidence on the Malaysian strategy of using rubber research to induce development was found to be consistent with the "induced development model." In the model technical and institutional change is treated as an endogenous to the development process, rather than an exogenous factor that operates independently of other development processes.

However, with a plantation export crop like rubber (98 percent of Malaysian production is exported), a part of the benefits from research paid for by the producers in Malaysia will go to the consumers abroad.[1] In addition, a portion of the profits and earnings of foreign-owned estates and factors will be repatriated.

In view of the unusual characteristics of rubber relative to the crops, mostly annuals, which have been the subject of earlier studies, an important consideration is whether the returns to producers in Malaysia will be high enough to justify Malaysia's investment on rubber research. Another important consideration from the Malaysian viewpoint is how producer benefits will be distributed between estates and smallholdings, and between different factors of production.

In measuring the returns from rubber research, the methodological framework used was the direct benefit cost or index number approach. This approach involves the following stages: (1) estimation of gross benefits, (2) estimation of research costs, and (3) estimation of rates of return.

Gross benefits were estimated by making use of the concept of "economic surplus" first established by Marshall a century ago and used by Griliches in his hybrid corn study. Data required for the purpose include price elasticities of supply and demand, the rate of shift in the production function, rubber prices, and a consumer price index to use as deflator. In view of differences in their organization, inputs, and ownership, it was felt warranted to treat the two producing

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[1]The share of consumer benefits will be inversely related to the elasticity of demand. Colonial powers apparently understood the principle that the gains from improved technology tend to be passed on to consumers of the product. The initial establishment of experiment stations by colonial powers in their colonies reflected recognition of this principle. From their point of view these investments paid off handsomely (Evenson, "Comparative Evidence on Returns to Investment in National and International Research Institutions," p. 218).

subsectors, estates and smallholdings, separately in the estimation process.

The cornerstone of rubber research is the development (breeding and selection) of high yielding materials. All other expenditures, research and non-research, incurred by the RRIM, Prang Besar, and other private research stations are complementary to this work. Thus all expenditures in connection with the problems of the rubber grower were included in the cost stream. To take only the direct cost of breeding and selection would be unrealistic. Aside from research station costs incurred in the development of high yielding materials, the other major component in the cost stream was the direct and associated costs of the officially sponsored post-War rubber replanting scheme. This replanting scheme had a dual objective to perform: (a) to countervail the threat of synthetic rubber competition, and (b) to resuscitate the dilapidated state of the industry. In the process it served as a catalyst in the rapid diffusion of high yielding materials to the industry.

The efficiency of investment on rubber research in Malaysia was assessed by bringing the benefit and cost streams together. Three common investment criteria were used in the assessment. These were the benefit-cost (B/C) ratio, net present value (NPV), and the internal rate of return (IRR).

The computations showed that the direct returns to rubber research investment are high, with internal rates of return of 24-25 percent when both producer and consumer benefits were taken into account. The rates are comparable to those obtained in some of the earlier studies on returns to research on annual crops. It is significant that these rates were obtained from rubber despite the fact that some of the earlier studies took account only of the direct cost of the breeding program. The cost stream for rubber included all expenditures incurred by the RRIM, Prang Besar, and other private research stations, as well as the direct and associated costs of the post-War replanting scheme.

Even when research benefits to producers in Malaysia (producer benefits) alone were considered in the revenue stream, estimated internal rates of return of about 12 percent were still greater than the estimated opportunity cost of capital of 10 percent in Malaysia. Hence, without taking secondary benefits into consideration, it appears that returns have been high enough to producers to fully justify Malaysia's investment on rubber research as socially profitable.

To ascertain if these estimates of internal rates of return are conservative, two sensitivity tests were made. In the first test, an alternative yield series for unselected materials to "correct" for the probable downward bias in yield because of the replanting scheme was used. The second test assumed that research costs and benefits were terminated in 1973. In both cases, the resulting internal rates of return were largely similar to the original estimates using deflated figures from 1932-1990.

Another factor can be advanced to suggest that the estimates are conservative. This is because no account of the income returned to the MRRDB by the RRIM from the sale of rubber and planting materials was taken in the computations that were made.

A third sensitivity test using current instead of deflated figures was also made to determine the relative stability of the

Malaysian cost-of-living over the period under study. This analysis decreased the internal rates of return by only 5 percent and suggests that the Malaysian cost-of-living during the study period was relatively stable.

When the issue of distribution of producer benefits is taken up, it is evident that the estate subsector has been the major beneficiary. The principal reason for this lies in the divergence in the net yield increase resulting from the use of high yielding materials, between the two subsectors. The net yield increase in smallholdings has been consistently smaller than that of estates. This is a reflection of the lag in replanting by smallholders, despite the availability of replanting grants.

The distribution of net social benefits between different factors of production is in inverse proportion to the elasticity of supply. While there is no statistical estimate available of either the elasticity of supply of land or the elasticity of supply of labor, it is known that the supply of land, which is a state matter, is for all practical purposes fixed. On the other hand, the high unemployment in the rural sector suggests that the supply of labor is highly elastic. The available evidence, although meager, seems to suggest that owners of rubber land have received most of the benefits from the use of high yielding materials.

Apart from the direct benefits of rubber research, there may be indirect contributions known as secondary benefits or linkages. Four basic categories of secondary benefits that have been identified include: (1) indirect benefits, (2) externalities, (3) dynamic secondary benefits, and (4) intangibles.

Indirect benefits of the induced by variety are apparently small. This is because rubber production is basically a simple process requiring few purchased intermediate inputs. As a consequence of the weak demand, there is little inducement to invest in input-producing industries.

Rubber manufacturing constitutes the only forward linkage or stemming from benefits. However, the rubber manufacturing industry is still on a small scale.

Externalities in the form of free inputs enjoyed by other industries can arise either as a result of economies of scale or through technological spillovers. In the rubber industry, the first type of externalities may be represented by the industry's demand for transportation services. The original transportation network which was developed to serve the tin and rubber industries led to the export-led growth of the western half of the country.

The role of the industry in promoting mass education is a component of dynamic secondary benefits. Although schools were supposed to be set up on all estates, the quality of education provided was poor and the curriculum lacked relevancy. Consequently, the dynamic secondary benefits created by the industry in the form of "improved attitudes" must be deemed small.

The intangible benefits generated have, however, been large. Rubber estates have long been engaged in the fight to eradicate malaria, dysentery, and other infectious diseases in the rural areas. The high quality of health and medical services provided by estates has meant that estate workers generally enjoy better medical care than most other rural dwellers.

Some Policy Implications

Lessons from the Malaysian Experience

The Malaysian success in rubber research as a development strategy must be attributed, in the main, to the foresight and confidence shown by the government and the industry in the potential of employing science and technology. Science has left its mark in two complementary ways. The application of agricultural science (plant breeding, physiology, disease control, etc.) has raised yield or productivity several fold over that of the original importations of *Hevea*. Research into the processing, properties, and application of rubber has transformed it from a raw material to a science based product. This was accomplished through the commitment of extensive resources by the private and public sector to a comprehensive and integrated program of basic and applied research. In turn this was complemented by a replanting scheme to diffuse high yielding materials and related innovations to the industry. Malaysia's use of rubber research as a strategy to promote development has shown that there are no short cuts to development, and that it takes resources, foresight, and dedication for success in pursuing agricultural research.

Role of Rubber Consuming Nations

The total return to investment on rubber research has been high. However, the fact that a part of the research benefits is received by consumers suggests that it may be in the interest of consuming countries to continue making it worthwhile for Malaysia to invest in rubber research. One way would be for consuming countries to support the efforts of rubber producers to set up a rubber buffer stock scheme to stabilize rubber prices. The machinery for such a scheme has in fact been set in motion by Malaysia and other producing member countries of the Association of Natural Rubber Producing Countries (ANRPC).

Role of Other Rubber Producing Nations

It was estimated that in recent years Malaysia alone has financed about 85 percent of all research on natural rubber. Since the output of research, knowledge and technology, has the attributes of a public good, the benefits of rubber research undertaken by Malaysia redound to the benefit of all producers of natural rubber. That Malaysia alone cannot continue to shoulder the burgeoning costs of rubber research, indefinitely, has become increasingly clear.[2]

More integrated and concerted international action among rubber producing nations on select problem areas is also called for. A case in point is the common threat posed by South American Leaf (SALB) to all rubber producing nations. Malaysia has maintained a research unit in Trinidad since 1961 to study the disease and screen susceptible planting materials to prevent the accidental introduction of SALB to the East. It is certainly in the interest of other rubber producing nations to contribute both funds and/or materials for research on SALB, and other problem areas. To ensure the viability of the natural rubber industry and the livelihood of some 30 million people dependent on the industry in Malaysia, Indonesia, Thailand,

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[2]This was the message in the speech of the Director of the RRIM, Tuan Haji Ani Arope, at the 1975 International Rubber Conference, held in Kuala Lumpur on October 1975.

Ceylon, Vietnam, and Singapore, it is imperative that rubber research should become the collective responsibility of all producing nations.

Increasing the Share of Research Benefits to Smallholders

To redress the earlier neglect and discrimination, more attention should be given to solving smallholder problems. The magnitude of the smallholder problem can best be appreciated in terms of the findings on poverty contained in the Third Malaysian Plan. According to the Plan, if account is taken "of the basic requirements for an average Malaysian household to maintain a family in good nutritional health as well as provide for minimum needs in respect of clothing, housing, household management and transport, . . . about one-half (or 800,000 households) were in poverty in 1970 out of 1.6 million households in Peninsular Malaysia. The largest number of these poor households was located in the rural areas and accounted for about 89 percent of all the poor with most of them in rubber smallholdings . . . ."[3]

Although replanting grants have been increased to encourage smallholders with less than 5 acres each to replant their obsolete trees with high yielding materials, the problem is more complex. For many of these smallholders rubber is their only source of monetary income. Unless supplementary sources of income can be provided to tide them over the long gestation period, there is little assurance that many of the problem smallholdings will be replanted by the owners of their own volition. Some form of "subsistence allowance" along

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[3]Third Malaysia Plan, 1976-1980, p. 72.

the lines provided to settlers in Federal land development schemes may be required.

Another measure is land consolidation to increase the size of "uneconomic" size holdings. The Federal Land Consolidation and Rehabilitation Authority (FELCRA) has been entrusted with this responsibility but, as yet, little has been accomplished.

Official concern over the continuing plight of rubber smallholders led to the passage of five rubber Bills by the Malaysian Parliament in 1972. This led to the establishment of the Rubber Industry Smallholders Development Authority (RISDA) in January 1973. A Smallholders Project Research Division was wet up by the RRIM to explore ways of speeding up adoption of research innovations by smallholders. It would adapt where necessary existing research innovations for immediate application to smallholdings, and investigate the feasibility of adopting various innovations such as advanced planting techniques to reduce the immaturity period, tree stimulation, and mixed cropping, among others. The responsibility for implementation of such innovation by smallholders, however, is vested with RISDA, which is responsible for all aspects of development in the smallholder subsector.

This division of responsibility in smallholder problems requires effective administration of the vertical processes involved from research to the smallholder in order to be effective. To ensure proper coordination of the vertical processes a Smallholders Panel of Consultants has been established by the MRRDB "to review smallholder problems, identify solutions available, and develop an implementation strategy" that impinges on the short and long term.[4] It is hoped that these new measures will enable smallholders to receive a bigger share of the benefits from rubber research.

Redistribution of Income

A detailed consideration of this vexatious issue is outside the scope of this study. It is of paramount importance since a basic tenet of the Malaysian government's "New Economic Policy" is the restructuring of Malaysian society and the redistribution of income.[5] It can be pointed out here, however, that income redistribution policies can often lead to a trade-off between income levels and employment.

Development of Rubber-Based Industries

It was earlier seen that secondary benefits in the industry are relatively small. One of the most promising areas where greater secondary benefits might be created is in the development of rubber-based industries. To this end a Technology Center was recently established at the RRIM to augment research on new uses for rubber and promote greater usage of rubber locally. By making available technological innovations to existing and new manufacturers of rubber products the pace of rubber-based manufacturing in the country, it is believed, can be accelerated.

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[4]Closing Address of the Controller, Tan Sri Dr. B. C. Sekhar, at the Rubber Research Institute of Malaysia 1976 Planters Conference held in Kuala Lumpur on October 1976.

[5]Third Malaysian Plan, pp. 7-10.

Suggestions for Further Research

This work represents a first attempt at quantifying returns from investment on rubber research in Peninsular Malaysia. While every effort was made to take cognizance of errors of omission and commission in earlier studies of this kind, it is recognized that there are still weaknesses in the data and methodology adopted. First, in some cases, the data such as smallholding yields, had to be approximated although in virtually all cases they were checked and/or verified with competent authorities or extant sources to the extent possible. Nevertheless there is still scope for further refinement of the data, especially those for smallholdings and replanting costs.

The second weakness is procedural and has to do with what is the appropriate methodology. It was pointed out in Chapter IV that there is still no clear consensus in the profession on this fundamental question. In this connection, two recent critiques of the conventional methodology used, which is based in large part on Griliches' hybrid corn study, by Lindner and Jarrett (1977), and Wise (1975), whose criticism also extended to production function analysis, deserve close attention and investigation. Time was a limiting factor in this study; and precluded consideration of these two important pieces of work. It is suggested that future studies on returns from agricultural research should take stock of them.

Another area that merits investigation is to estimate the relative returns to rubber research *per se* and returns to the diffusion of research innovations (what Hertford and Schmitz term as "the delivery system"). If it is discovered that returns from the dissemination of research innovations are higher than from research, then it would be logical to commit more resources to this activity.

To enable a better understanding of the diffusion process in rubber it is suggested that more research be undertaken. Studies should be conducted to determine why there is a lag in the diffusion of high yielding materials and other research innovations between estates and smallholdings. Answers need to be found to overcome the bottlenecks that impede the adoption and acceptance of research innovations by those in most need of them.

It was indicated in Chapter III that most new rubber clones and clonal seedlings bred in Malaysia are in fact joint products of national (private and public sector) and international (mostly Indonesian) research efforts. In turn, most of the important international, particularly Indonesian, clones can be directly traced to the original twenty-two Wickham seedlings brought to Singapore (then part of British Malaya) in 1877 from the Royal Botanic Gardens at Kew, England. This makes it difficult to delineate the contributions of different organizations, national and international. Recently, however, Evenson has attempted this difficult task with high yielding rice varieties.[6] Similar work on rubber, although likely to be more complex, should produce some interesting side results.

A related investigation would be to develop a method for assessing the impact on the demand for Malaysian rubber arising from "retaliatory" measures by other natural rubber producing countries

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[6]Evenson, "Comparative Evidence on Returns to Investment in National and International Research Institutions," pp. 251-54.

either through stepping up their own research efforts or subsidization of their producers, or through a combination of both measures. Such reaction on the part of other rubber producing nations could shift the demand curve for Malaysian rubber to the left. This could affect the returns to investment on rubber research in Malaysia.

APPENDIX A

BASIC DATA ON CONTRIBUTION OF RUBBER, RESEARCH CESS AND EXPENDITURES, AND ESTATE LABOR FORCE

Table A.1.--Contribution of Rubber Export Proceeds (REP) to Gross Domestic Product (GDP) and Gross Export Proceeds (GEP) in Millions of Current Dollars.

Year	GDP[a]	GEP	REP	REP/GDP	REP/GEP
				Percent	
1947	2654	835	587	22.1	70.3
1948	2494	1116	680	27.3	60.9
1949	2391	1179	590	24.7	50.0
1950	4137	2608	1870	43.8	69.4
1951	5550	3379	2445	44.1	72.4
1952	4693	2134	1287	27.4	60.3
1953	4271	1598	896	21.0	56.1
1954	4208	1625	903	21.5	55.6
1955	5094	2370	1584	31.1	66.8
1956	5111	2262	1378	29.0	60.9
1957	4929	2180	1304	26.5	59.8
1958	4753	1882	1197	25.2	63.6
1959	5527	2476	1722	31.2	69.5
1960	5626	2927	1829	32.5	62.5
1961	5646	2626	1442	25.5	54.9
1962	6000	2626	1368	22.8	52.1
1963	6362	2705	1374	21.6	50.8
1964	6805	2781	1303	19.2	46.9
1965	7411	3103	1368	18.5	44.1
1966	7780	3120	1396	17.9	44.7
1967	8146	2919	1216	14.9	41.7
1968	8424	3217	1301	15.4	40.0
1969	9218	4076	1940	21.1	47.6
1970	9522	4192	1663	17.5	39.7
1971	10038	3917	1417	14.1	36.2
1972	10699	4043	1261	11.8	31.2
1973	11913	6027	2396	20.0	39.8

[a]At Market Price.

Sources: Department of Statistics, National Accounts of West Malaysia (Kuala Lumpur, various issues)
GDP (1960-1973): Treasury, Economic Report (Kuala Lumpur, 1974/75).

Table A.2.--Rubber Research Cess, RRIM Expenditure and Gross Domestic Product.

Year	GDP	Research Cess	RRIM Expenditure	Res. Cess / GDP	RRIM Exp. / Res. Cess
	($ Million)	($ Thousand)		Percent	
1947	2654	3613	1248	0.14	34.54
1948	2494	3891	1820	0.16	46.77
1949	2391	4535	2144	0.19	47.28
1950	4137	7279	2293	0.18	31.50
1951	5550	4686	2802	0.08	59.80
1952	4693	4901	3331	0.10	67.97
1953	4271	6087	3582	0.14	58.85
1954	4208	6380	3327	0.15	52.15
1955	5094	6847	3506	0.13	51.20
1956	5111	6675	4044	0.13	60.58
1957	4929	6834	4488	0.14	65.67
1958	4753	10200	5554	0.21	54.45
1959	5527	12098	5894	0.22	48.72
1960	5626	11534	6925	0.23	60.04
1961	5646	11876	7378	0.24	62.13
1962	6000	12022	8181	0.23	68.05
1963	6362	13101	9093	0.23	69.41
1964	6805	13598	10029	0.22	73.75
1965	7411	16392	10733	0.25	65.48
1966	7780	17695	12337	0.26	69.72
1967	8146	19522	12496	0.28	64.01
1968	8424	23931	12801	0.33	53.49
1969	9218	27026	13466	0.33	49.83
1970	9522	27620	14477	0.36	52.41
1971	10038	28733	14716	0.38	51.22
1972	10699	28427	16325	0.35	57.43
1973	11913	38177	18638	0.33	48.82

Sources: GDP: As in Table A.1.
Research Cess: Estimated, based on rate of research cess and annual rubber exports.
RRIM Expenditure: Rubber Research Institute of Malaya Annual Report (Kuala Lumpur, various issues).

Table A.3.--Labor Force Employed on Estates by Race (Thousands of Workers).

Year	Malays	Chinese	Indians	Others
1933	12.0	39.8	102.2	0.5
1934	35.0	85.6	177.8	1.3
1935	24.8	60.2	173.5	0.7
1936	27.2	63.6	183.2	0.6
1937	34.2	74.9	236.9	0.6
1938	24.3	59.8	208.3	0.4
1939	33.0	73.5	213.4	0.3
1940				
1946	60.1	96.2	175.6	0.4
1947	59.0	78.6	150.9	0.7
1948	61.5	73.6	151.5	0.4
1949	57.4	70.9	146.7	0.8
1950	54.8	77.2	148.5	1.1
1951	52.3	80.0	149.0	1.5
1952	55.0	76.8	146.8	1.4
1953	49.0	75.9	136.0	0.4
1954	54.7	81.6	135.1	0.8
1955	49.8	82.0	144.9	1.5
1956	51.9	83.4	143.8	1.1
1957	52.5	80.3	142.6	1.3
1958	n.a.	n.a.	n.a.	n.a.
1959	56.2	85.7	139.8	0.8
1960	60.8	85.5	138.2	0.8
1961	66.1	83.3	135.4	0.8
1962	66.5	82.2	136.7	0.8
1963	67.6	81.8	136.1	0.8
1964	61.1	82.8	130.7	0.8
1965	62.3	79.7	127.5	0.6
1966	60.0	77.2	111.8	0.5
1967	55.9	70.0	105.5	0.5
1968	47.2	64.0	95.1	0.4
1969	51.5	65.0	98.2	0.4
1970	62.4	69.7	93.8	0.5
1971	63.8	54.4	79.8	0.7
1972	64.1	51.8	79.5	0.9
1973	64.1	46.2	80.9	0.5

Source: Department of Statistics, Rubber Statistics Handbook (Kuala Lumpur, various issues).

APPENDIX B

PROCEDURE FOR ADJUSTING YIELD OF UNSELECTED MATERIAL

Table B.1.--Estimated Yields for Unselected Seedling Materials if High Yielding Materials were not Available (in Pounds Per Acre).

Year	$Y=600-159.09211(0.9216)^t$	(t)
1927	447	1
1928	458	2
1929	458	3
1930	464	4
1931	469	5
1932	474	6
1933	479	7
1934	488	8
1935	488	9
1936	492	10
1937	496	11
1938	500	12
1939	504	13
1940	507	14
1941	511	15
1942	514	16
1943	517	17
1944	521	18
1945	524	19
1946	526	20
1947	529	21
1948	532	22
1949	534	23
1950	537	24
1951	539	25
1952	542	26
1953	544	27
1954	546	28
1955	548	29
1956	550	30
1957	552	31
1958	554	32
1959	555	33
1960	557	34
1961	559	35
1962	560	36
1963	562	37
1964	563	38
1965	565	39
1966	566	40

Table B.1.--Continued

Year	$Y=600-159.09211(0.9216)^t$	(t)
1967	567	41
1968	569	42
1969	570	43
1970	571	44
1971	572	45
1972	573	46
1973	574	47
1974	575	48
1975	576	49
1976	577	50

A modified exponential curve (E) was fitted by first assuming a maximum level (K) of 600 pounds per acre. The constants a and b were determined by requiring the curve to pass through two points. The first point was the estimated average yield of unselected materials on estates for the years 1927-1932. This gives the point Y=461 and t=3.5. The second point was obtained by taking the average of the mean yield figures for 1937 and 1938, and 1947, i.e.,

$$\left[\left(\frac{\text{Figures for 1937 and 1938}}{2} + \text{figure for 1947}\right) + 2\right]$$

This gives y = 515 and t = 16.25. The equations (I and II), see below, were solved for a and b. The choice of years to represent average yields was based on practical judgment and after taking into account fluctuations due to specific reasons.

$$Y = K + ab^t \text{ ....(E)}$$

where Y = yield in pounds per acre

K = Expected maximum yield of 600 pounds per acre.

Year	Estate Unselected seedling yield	t
	-------(lb/ac (Y))-------	
1927	408	1
1928	426	2
1929	474	3
1930	489	4
1931	487	5
1932	483	6
Average(1927-32)	461	3.5...(A)
1937	516	11
1938	466	12
Average(1937-38)	491	11.5...(1)
1947	539	21 ...(2)
Average of (1) & (2)	515	16.25..(B)

$Y = K + ab^t$

From (A) $461 = 600 + ab^{3.5}$.............(I)

From (b) $515 = 600 + ab^{16.25}$..........(II)

From (I) & (II): $a = -159.0921$ and $b = 0.96216$

$\therefore \quad Y = 600 - 159.0921(0.96216^t)$

APPENDIX C

PRICES OF RIBBED SMOKED SHEETS (RSS) AND STANDARD MALAYSIAN RUBBER (SMR) GRADES

Table C.1.--Average Prices of Ribbed Smoked Sheets (RSS) and Standard Malaysian Rubber (SMR), By Grades in Cents per Pound.

Year	RSS					SMR					
	1	2	3	4	5	SCV	SL	5	10	20	50
1925	113.97										
1926	80.49	(78.49)	(76.89)								
1927	64.32	(62.32)	(60.76)								
1928	36.76	(34.76)	(33.16)								
1929	34.47	(32.47)	(30.87)								
1930	19.16	(17.16)	(15.56)								
1931	10.09	(8.09)	(6.49)								
1932	6.80	(4.80)	(3.20)								
1933	10.21	(8.21)	(6.61)								
1934	19.84	(17.84)	(16.24)								
1935	20.19	(18.19)	(16.59)								
1936	26.99	(24.99)	(23.39)								
1937	32.09	(30.09)	(28.49)								
1938	24.04	(22.04)	(20.44)								
1939	30.96	(28.96)	(27.36)								
1940	37.54	(35.54)	(33.94)								
1941	38.56	(36.56)	(34.96)								
1947	37.31	(35.31)	(33.71)								
1948	42.18	(40.18)	(38.58)								
1949	38.22	(36.22)	(34.62)								
1950	108.18	106.14	104.33								
1951	169.53	163.29	156.83								
1952	96.39	92.19	88.68								
1953	67.59	65.20	62.71								
1954	67.02	66.57	65.43								
1955	113.74	110.56	108.07								
1956	97.18	94.92	93.89								

Table C.1.--Continued

Year	RSS					SMR					
	1	2	3	4	5	SCV	SL	5	10	20	50
1957	88.79	87.09	85.73								
1958	80.17	77.68	74.16								
1959	101.38	100.13	99.22								
1960	108.30	106.94	105.12								
1961	83.46	82.78	81.76								
1962	78.25	77.45	75.86								
1963	72.46	71.90	70.53								
1964	68.15	67.93	67.13								
1965	70.08	69.63	68.72								
1966	65.43	64.75	63.96								
1967	54.09	52.73	51.37	50.12	46.72						
1968	53.18	52.05	51.37	50.80	48.88						
1969	69.85	69.29	68.61	68.04	66.34						
1970	56.47	55.11	54.09	53.18	51.82						
1971	46.04	42.86	41.96	41.28	39.92						
1972	42.41	40.60	39.92	39.24	38.22	45.13	43.66	42.30	40.82	40.60	39.69
1973	75.07	71.90	71.10	69.85	68.15	78.02	76.32	74.16	72.01	71.78	68.95
1974	81.53	75.98	72.92	71.21	69.40	87.77	85.84	78.70	73.37	72.80	68.95
1975	62.03	59.99	58.97	58.06	57.49	65.09	63.84	61.92	60.33	59.76	58.51
1976	90.27	87.20	86.07	84.48	83.35	97.86	96.62	90.27	86.64	86.07	85.28

Source: Rubber Research Institute of Malaysia, Applied Economics and Statistics Division (1977).

Figures in parentheses indicate they are estimated.

APPENDIX D

WEIGHTED CURRENT PRICES OF FERTILIZERS

Table D.1.--Weighted Current Prices of Fertilizers in Peninsular Malaysia, 1931-1973.

Year	Ammonia Sulphate	CIRP	Muriate of Potash	Weighted Average[a]	Weighted Average Price[b]
	(Dollars per Ton)				(Cents per Pound)
1931-36	n.a.	n.a.	n.a.	(71.6)	(3.2)
1937	71.6	33.0	110.2	71.6	3.2
1938	71.6	33.0	110.2	71.6	3.2
1939	72.8	33.0	110.7	72.3	3.3
1940	112.2	36.4	147.6	102.1	4.6
1941	146.6	36.4	196.8	131.6	6.0
1946-48	n.a.	n.a.	(270.6)	(206.9)	(9.4)
1949	239.1	78.7	270.6	206.9	9.4
1950	239.1	88.6	270.6	209.4	9.5
1951	257.8	90.1	270.6	219.1	9.9
1952	251.0	113.2	270.6	221.5	10.0
1953	211.6	113.2	236.2	193.2	8.8
1954	221.4	113.2	236.2	198.1	9.0
1955	231.3	113.2	236.2	203.0	9.2
1956	237.1	116.0	240.3	207.6	9.4
1957	259.3	141.1	271.7	232.9	10.6
1958	214.0	133.0	245.0	201.5	9.1
1959	195.0	125.0	210.0	181.3	8.2
1960	195.0	125.0	210.0	181.3	8.2
1961	185.0	125.0	220.0	178.8	8.1
1962	175.0	125.0	210.0	171.3	7.8
1963	185.0	125.0	220.0	178.8	8.1
1964	208.7	127.4	227.9	193.2	8.8
1965	225.0	118.1	225.0	198.3	9.0
1966	235.0	120.6	235.0	206.4	9.4
1967	235.0	120.6	235.0	206.4	9.4
1968	235.0	120.6	205.0	198.9	10.4[c]
1969	240.0	125.5	175.0	195.1	10.7
1970	240.0	125.5	208.0	203.4	10.5
1971	240.0	125.5	239.5	211.3	10.7
1972	210.0	130.4	239.5	197.5	10.7
1973	240.0	130.4	239.5	212.5	11.6

[a]Fertilizer prices were supplied by I.C.I. Agriculture (Malaysia) Sdn. Berhad.

[b]From 1931-67, weighted prices were based on 50% Ammonia Sulphate, 25% Christmas Island Rade Phosphate (CIRP), and 25% Muriate of Potash.

[c]From 1968-73, figures used were adapted from published figures given in the Department of Statistics, Rubber Statistics Hand Book (Kuala Lumpur, various issues).

APPENDIX E

ESTIMATES OF SOCIAL BENEFITS FROM RUBBER RESEARCH

Table E.2.--Estimates of Social Benefits from Rubber Research (When n = -0.5; e_E = 0, e_S = 0.5) in Thousands of 1963 Dollars.

Year	Producers' Gain			Consumers' Gain			Total Social Benefits		
	Estates	Smallholdings	Total	Estates	Smallholdings	Total	Estates	Smallholdings	Total
1932	-215.9	0.0	-215.9	432.7	0.0	432.7	216.8	0.0	216.8
1933	-739.3	0.0	-739.3	1485.5	0.0	1485.5	746.2	0.0	746.2
1934	-2124.6	0.0	-2124.6	4276.5	0.0	4276.5	2151.9	0.0	2151.9
1935	-3890.1	0.0	-3890.1	7879.2	52.9	7932.1	3989.1	52.9	4042.0
1936	-7576.7	0.0	-7576.7	15451.0	185.0	15636.1	7874.3	185.1	8059.4
1937	-9530.5	0.1	-9530.4	19350.9	186.7	19537.6	9820.4	186.7	10007.2
1938	-11714.2	0.8	-11713.4	24210.9	481.1	24692.0	12496.7	481.9	12978.6
1939	-24088.8	2.1	-24086.7	50915.7	924.0	51839.6	26826.9	926.1	27752.9
1940	-19526.3	0.3	-19526.0	40057.7	551.7	40609.4	20531.3	552.1	21083.4
1941	-20056.9	0.3	-20056.6	41146.1	568.3	41714.4	21089.2	568.7	21657.9
1946	-52304.4	12.5	-52291.9	112110.1	3549.4	115659.6	59805.7	3562.0	63367.6
1947	-15739.4	0.8	-15738.6	33736.2	564.4	34300.5	17996.7	565.2	18561.9
1948	-23018.4	1.8	-23016.6	50014.7	888.0	50902.8	26996.3	889.8	27886.1
1949	-27750.2	5.1	-27745.0	62599.0	1366.8	63965.8	34848.8	1372.0	36220.8
1950	-81401.7	2.9	-81398.8	189671.1	1848.5	191519.5	108269.4	1851.3	110120.7
1951	-111846.2	43.8	-111802.4	283660.6	7223.9	290884.6	171814.5	7267.7	179082.2
1952	-68309.6	48.5	-68261.1	177510.9	5295.9	182806.8	109201.3	5344.4	114545.7
1953	-50281.6	40.2	-50241.4	132261.5	4022.8	136284.3	81979.9	4063.0	86042.9
1954	-54093.7	51.7	-54042.1	141873.8	4927.5	146801.3	87780.1	4979.2	92759.2
1955	-100584.7	52.0	-100532.7	268948.6	7069.2	276017.7	168363.9	7121.2	175485.1
1956	-89439.1	62.3	-89376.8	249113.2	6787.7	255900.9	159674.1	6850.0	166524.1
1957	-85620.3	74.5	-85545.8	251720.0	6846.7	258566.7	166099.7	6921.2	173020.9
1958	-84697.3	98.0	-84599.2	259396.9	7308.9	266705.9	174699.6	7407.0	182106.6
1959	-117788.4	179.9	-117608.5	379479.7	11946.2	391425.9	261691.3	12126.1	273817.4
1960	-128958.5	325.3	-128633.2	441905.3	16813.1	458718.4	312946.9	17138.4	330085.3
1961	-102508.7	442.7	-102066.0	389294.6	17469.0	406763.6	286785.8	17911.8	304697.6
1962	-93957.4	760.5	-93196.9	410935.9	21913.1	432848.9	316978.6	22673.6	339652.2
1963	-82488.6	1277.0	-81211.7	413917.6	27729.9	441647.6	331429.1	29006.9	360435.9
1964	-70558.9	2062.3	-68496.6	440113.7	35439.9	475553.7	369554.8	37502.3	407057.1
1965	-59845.2	3378.9	-56466.3	499873.7	48097.1	547970.7	440028.5	51476.0	491504.5
1966	-30112.9	5410.8	-24702.1	525303.4	61113.0	586416.4	495190.6	66523.7	561714.3
1967	2041.8	8419.3	10461.1	456618.7	67094.9	523713.7	458660.6	75514.2	534174.8
1968	13977.1	10783.4	24760.5	493128.1	82696.0	575824.1	507105.1	93479.4	600584.6
1969	104618.9	10337.4	114956.3	745864.5	105694.2	851558.7	850483.5	116031.6	966515.1
1970	119470.6	28198.8	147669.3	627339.8	148910.4	776250.2	746810.3	177109.1	923919.4
1971	127519.2	54910.0	182429.2	547837.6	177007.7	724845.4	675356.9	231917.7	907274.7
1972	134268.6	94469.1	228737.7	495464.9	212398.2	707863.1	629733.4	306867.3	936600.7
1973	281536.6	26841.6	308378.1	831232.9	180744.2	1011977.0	1112769.0	207585.8	1320355.0

Assumptions: Prices Received by Estates are based on RSS 1
Prices Received by Smallholdings are based on RSS 3

Table E.3.--Estimates of Social Benefits from Rubber Research (When $n = -1.0$; $e_E = 0$, $e_S = 0.5$) in Thousands of 1963 Dollars.

Year	Producers' Gain			Consumers' Gain			Total Social Benefits		
	Estates	Smallholdings	Total	Estates	Smallholdings	Total	Estates	Smallholdings	Total
1932	0.3	0.0	0.3	216.4	0.0	216.4	216.7	0.0	216.7
1933	2.3	0.0	2.3	742.8	0.0	742.8	745.1	0.0	745.1
1934	9.1	0.0	9.1	2138.3	0.0	2138.3	2147.4	0.0	2147.4
1935	33.0	17.6	50.6	3939.6	35.2	3974.9	3972.6	52.9	4025.5
1936	99.2	61.8	160.9	7725.5	123.4	7848.9	7824.7	185.1	8009.8
1937	96.7	62.3	158.9	9675.5	124.4	9799.9	9772.1	186.7	9958.8
1938	260.8	161.0	421.9	12105.5	320.7	12426.2	12366.3	481.7	12848.0
1939	912.7	309.8	1222.4	25457.8	615.8	26073.7	26370.5	925.6	27296.1
1940	335.0	184.2	519.2	20028.8	367.8	20396.6	20363.8	552.0	20915.8
1941	344.1	189.7	533.8	20573.1	378.9	20951.9	20917.1	568.6	21485.7
1946	2500.4	1193.8	3694.2	56055.1	2365.4	58420.4	58555.4	3559.2	62114.6
1947	752.4	180.8	941.3	16868.1	376.2	17244.3	17620.5	565.0	18185.5
1948	1326.0	297.5	1623.5	25007.4	591.9	25599.3	26333.3	889.4	27222.7
1949	2366.2	460.0	2826.2	31299.5	910.8	32210.3	33665.7	1370.8	35036.5
1950	8955.9	618.6	9574.5	94835.5	1232.1	96067.6	103791.4	1850.7	105642.1
1951	19989.4	2445.3	22434.7	141830.3	4812.7	146643.0	161819.7	7258.0	169077.7
1952	13630.6	1806.6	15437.2	88755.4	3527.0	92282.4	102386.0	5333.6	107719.6
1953	10566.1	1375.2	11941.2	66130.7	2678.9	68809.6	76696.8	4054.1	80750.9
1954	11228.8	1686.5	12915.3	70936.9	3281.2	74218.1	82165.7	4967.7	87133.4
1955	22593.0	2400.7	24993.7	134474.3	4709.0	139183.2	157067.2	7109.6	164176.9
1956	23411.7	2315.6	25727.3	124556.6	4520.5	129077.1	147968.3	6836.1	154804.4
1957	26826.5	2345.7	29172.2	125860.0	4559.0	130418.9	152686.4	6904.7	159591.1
1958	30000.8	2519.8	32520.6	129698.5	4865.4	134563.9	159699.2	7385.2	167084.4
1959	47967.6	4135.3	52102.9	189739.9	7950.8	197690.7	237707.5	12086.1	249793.6
1960	61329.4	5881.5	67210.9	220952.7	11184.6	232137.3	282282.0	17066.1	299348.1
1961	61425.7	6200.2	67625.9	194647.3	11613.2	206260.6	256073.1	17813.4	273886.4
1962	74340.3	7952.2	82292.5	205467.9	14552.4	220020.3	279808.2	22504.6	302312.8
1963	82980.1	10331.1	93311.2	206958.8	18392.0	225350.9	289938.9	28723.1	318662.0
1964	99665.3	13570.1	113235.4	220056.9	23473.9	243530.7	319722.2	37044.0	356766.1
1965	126727.7	18910.7	145638.4	249936.9	31814.4	281751.3	376664.7	50725.1	427389.9
1966	155025.8	24980.2	180006.0	262651.7	40341.2	302992.9	417677.6	65321.4	482998.9
1967	153567.5	29536.9	183104.4	228309.4	44106.3	272415.7	381875.7	73643.2	455520.0
1968	173694.1	36751.2	210445.2	246564.1	54331.9	300895.9	420257.9	91083.1	511341.1
1969	318367.4	44037.3	362404.7	372932.2	69697.1	442629.3	691299.7	113734.4	805034.1
1970	288760.3	73657.9	362418.2	313669.9	97184.8	410854.7	602430.4	170842.8	773273.2
1971	267625.3	105777.7	373403.1	273918.8	113937.7	387856.6	541544.0	219715.4	761259.4
1972	254667.3	151273.1	405940.4	247732.4	134601.1	382333.5	502399.7	285874.2	788274.0
1973	464768.6	83113.1	547881.7	415616.4	118507.9	534124.3	880385.4	201620.9	1082006.0

Assumptions: Prices Received by Estates are based on RSS 1
Prices Received by Smallholdings are based on RSS 3

Table E.4.--Estimates of Social Benefits from Rubber Research (When n = -2.0; e_E = 0; e_S = 0.5) in Thousands of 1963 Dollars.

Year	Producers' Gain			Consumers' Gain			Total Social Benefits		
	Estates	Smallholdings	Total	Estates	Smallholdings	Total	Estates	Smallholdings	Total
1932	108.4	0.0	108.4	108.2	0.0	108.2	216.6	0.0	216.6
1933	373.1	0.0	373.1	371.4	0.0	371.4	744.5	0.0	744.5
1934	1076.0	0.0	1076.0	1069.1	0.0	1069.1	2145.1	0.0	2145.1
1935	1994.6	31.7	2026.3	1969.8	21.1	1991.0	3964.4	52.9	4017.2
1936	3937.1	111.1	4048.2	3862.8	74.0	3936.8	7799.9	185.1	7985.0
1937	4910.2	112.0	5022.3	4837.7	74.7	4912.4	9748.0	186.7	9934.7
1938	6248.4	289.2	6537.6	6052.7	192.4	6245.1	12301.1	481.6	12782.7
1939	13413.4	555.8	13969.2	12728.9	369.4	13098.3	26142.3	925.2	27067.6
1940	10265.7	331.3	10596.9	10014.4	220.7	10235.1	20280.1	551.9	20832.0
1941	10544.6	341.2	10885.8	10286.5	227.3	10513.8	20831.1	568.5	21399.6
1946	29902.8	2138.2	32041.0	28027.5	1418.8	29446.3	57930.4	3557.0	61487.3
1947	8998.4	339.2	9337.6	8434.0	225.7	8659.7	17432.4	564.9	17997.3
1948	13498.2	534.0	14032.2	12503.7	355.1	12858.8	26001.8	889.1	26891.0
1949	17424.4	823.6	18248.0	15649.8	546.3	16196.1	33074.2	1369.9	34444.1
1950	54134.7	1111.0	55245.7	47417.8	739.2	48156.9	101552.5	1850.2	103402.7
1951	85907.2	4364.1	90271.4	70915.1	2886.1	73801.2	156822.4	7250.2	164072.6
1952	54600.7	3210.5	57811.2	44377.7	2114.5	46492.2	98978.4	5325.0	104303.4
1953	40989.9	2441.0	43430.9	33065.4	1605.9	34671.3	74055.3	4046.9	78102.2
1954	43890.0	2991.6	46881.7	35468.5	1966.9	37435.3	79358.5	4958.5	84317.0
1955	84181.9	4276.9	88458.8	67237.1	2823.5	70060.6	151419.1	7100.4	158519.5
1956	79837.1	4115.0	83952.1	62278.3	2710.1	64988.4	142115.4	6825.1	148940.4
1957	83049.9	4158.7	87208.6	62930.0	2732.7	65662.7	145979.9	6891.4	152871.4
1958	87349.8	4452.0	91801.8	64849.2	2915.7	67764.9	152199.1	7367.7	159566.8
1959	130845.7	7290.0	138135.7	94869.9	4764.1	99634.0	225715.6	12054.1	237769.7
1960	156473.4	10309.1	166782.5	110476.3	6699.2	117175.5	266949.7	17008.3	283958.0
1961	143392.9	10782.5	154175.4	97323.6	6952.2	104275.8	240716.6	17734.7	258451.3
1962	158489.2	13665.0	172154.2	102733.9	8704.4	111438.3	261223.2	22369.4	283592.6
1963	165714.5	17506.3	183220.8	103479.4	10989.8	114469.2	269193.9	28496.1	297690.0
1964	184777.4	22666.3	207443.8	110028.4	14011.0	124039.4	294805.9	36677.3	331483.2
1965	220014.2	31155.9	251170.2	124968.4	18968.5	143936.9	344982.6	50124.4	395107.0
1966	247595.2	40347.1	287942.4	131325.9	24012.3	155338.2	378921.1	64359.4	443280.5
1967	229330.3	45982.1	275312.4	114154.7	26164.4	140319.1	343484.9	72146.5	415631.4
1968	253552.6	56950.3	310502.9	123282.0	32215.7	155497.7	376834.7	89166.0	466000.7
1969	425241.7	70445.9	495687.6	186466.1	41450.7	227916.8	611707.8	111896.7	723604.5
1970	373405.2	108521.4	481926.6	156834.9	57308.3	214143.2	530240.2	165829.6	696069.9
1971	337678.4	143543.4	481221.8	136959.4	66410.3	203369.7	474637.7	209953.7	684591.5
1972	314866.7	191677.9	506544.6	123866.2	77401.7	201268.0	438732.9	269079.7	707812.6
1973	556384.7	126698.7	688083.4	207808.2	70150.4	277958.6	764193.1	196849.2	961042.2

Assumptions: Prices Received by Estates are based on RSS 1
Prices Received by Smallholdings are based on RSS 3

APPENDIX F

NET PRESENT VALUE (NPV) AND BENEFIT-COST (B/C) RATIOS FROM INVESTMENT ON RUBBER RESEARCH

Table F.3.--Net Present Values from Investment on Rubber Research Assuming Different Price Elasticities of Supply and Demand, and 10 Percent Discount Rate, When Yields of Unselected Materials are adjusted, 1918-1990 (Millions of 1963 Dollars).

NPV	n / (e_E, e_S)	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	201.74	165.85	147.46	138.07
	(0,0.50)	200.27	165.11	147.16	137.97
Producer	(0,0.25)	-288.69	-85.74	19.20	73.14
	(0,0.50)	-276.93	-80.11	21.37	73.84

Assumptions: P_E = RSS1 P_S = RSS3

Table F.4.--Benefit-Cost Ratios from Investment on Rubber Research Assuming Different Price Elasticities of Supply and Demand, and 10 Percent Discount Rate, When Yields of Unselected Materials are Adjusted, 1918-1990 (Based on 1963 Dollars).

B/C Ratio	n / (e_E, e_S)	-0.25	-0.5	-1.0	-2.0
Total	(0,0.25)	9.87	8.29	7.49	7.07
	(0,0.50)	9.81	8.26	7.47	7.07
Producer	(0,0.25)	-11.70	-2.77	1.84	4.22
	(0,0.50)	-11.18	-2.52	1.94	4.25

Assumptions: P_E = RSS1 P_S = RSS3

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