PN-AAX-186

50310

CHANGES IN SMALL-FARM RICE THRESHING TECHNOLOGY IN THAILAND AND THE PHILIPPINES

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ABSTRACT

Development and extension of the IRRI-designed axial-flow thresher led to its very rapid adoption among rice farmers in Thailand and the Philippines beginning in 1974. Made widely available to local manufacturers in both countries, the machines were profitable to own and easy to use compared with traditional threshing methods. Development of contract services was rapid and widespread. Significant reductions in threshing labor were found in both countries, and slight output gains were observed in the Philippines.

IRRI invested US$1.5 million in the development and extension of the thresher. The amount represents 2.6% of the value of machines sold during the same period. Returns to investment in engineering design of the thresher were high, but lower than funds expended at IRRI for varietal improvement and management research. Policy-induced economic distortions in exchange rates and credit policies that affected adoption of the thresher were minor in Thailand, but significantly increased the private profitability of the machine in the Philippines.

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Threshing is the terminal operation in rice production. In most small-scale production systems, it is also the point where benefits are shared among farmers, laborers, landlords, and creditors. Over long periods of time, most cultural systems have developed sharing arrangements that ensure an equitable partitioning of the crop among those whose resources (labor, land, and capital) have produced it, including those within the community who have no access to land. The introduction of new technology tends to disrupt these arrangements, and new systems of sharing emerge to replace older forms. As Hayami and Kikuchi (14) and Kikuchi et al (25) have pointed out, innovations may raise production levels, but the gains obtained often create pressures for a redivision of the crop shares. Seeking to maximize shares initiates a process of adjustment among those who own productive resources such as land and water and those who provide essential services such as labor. The final equilibrium may, in large measure, depend on such factors as the relative economic power or position that each group holds in the village or community, the existence of alternative employment opportunities, and the strength of established kinship relationships among groups. These factors in turn interact with economic variables in determining the speed and extent to which new threshing technologies are adopted.

In both Thailand and the Philippines there has been a very rapid shift from traditional to mechanical threshing techniques over the past 10 yr. The technical basis for this change was the development and extension of the axial-flow thresher by the International Rice Research Institute (IRRI) located in the Philippines. The story of the machine's development and promotion through an international network of public institutions and private manufacturing enterprises provides the first major focus of this study. Of particular interest are the factors that persuaded IRRI to invest resources in engineering development activities.

A second theme examines the output and distributive effects of the mechanical thresher on farmers, on hired labor, and, through backward linkages, on employment and income in the nonagricultural sector. Included is an evaluation of the financial profitability of the thresher and how this has been affected by changing resource and product prices, utilization levels, the stock of machines, and the institutional arrangement for contract services.

A third section examines policies and public sector programs that have facilitated acceptance and diffusion of the axial-flow thresher. It also examines the level of resource commitment provided by IRRI and attempts to evaluate the benefits that have resulted from this investment in engineering design and development activities.

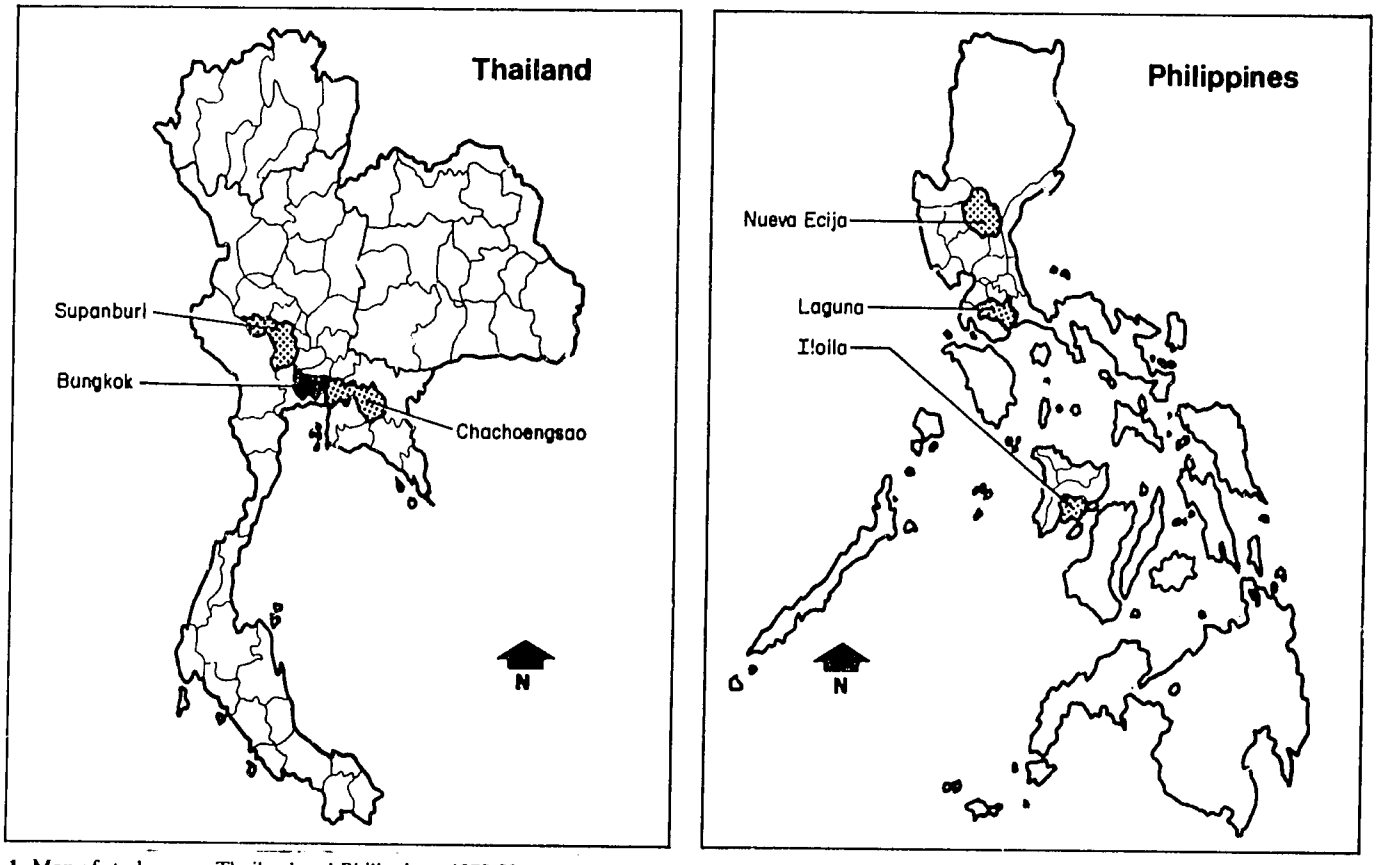
To evaluate the adoption patterns and the farm-level impact of the axial-flow threshers, a series of field surveys of thresher owners, users, and nonusers was undertaken at two sites (Laguna and Iloilo) in the Philippines and two sites in Thailand (Fig. 1). A broad profile of the 369 respondents included in these studies is shown in Table 1. A survey of 64 landless workers involved in threshing operations was also conducted in Nueva Ecija, Philippines (12). These special surveys were supplemented by interviews with thresher manufacturers (30) and reports of engineers (23, 24), financial institutions (36), and national and international organizations actively supporting agricultural engineering design and development activities.

DEVELOPMENT OF THE AXIAL-FLOW THRESHER

IRRI machinery program

Beginning with special project funds in 1967, engineers at IRRI focused on the design of equipment for small rice farmers (10). The rationale for small, low-cost farm machinery was the belief that private firms in most rice-producing countries lacked viable designs and the resources to develop them. In addition, it was felt that the absence of suitable patent protection and incentives to invest in research and development (R&D) activities made it unlikely that the private sector would produce such designs in the short and medium run.

The fabrication of simple farm equipment in Third World countries is carried out by small- and medium-scale companies, usually servicing a very localized market and using designs copied from competitors' or imported models. Innovations that demonstrate ready market acceptance and are easily fabricated are quickly imitated. Unless the design is complex, uses unusual materials or methods in its fabrication, or has a tightly circumscribed market, there is little an innovator can do to protect it from being copied or to capture or restrict the benefits from its use.



1. Map of study areas, Thailand and Philippines, 1978-83.

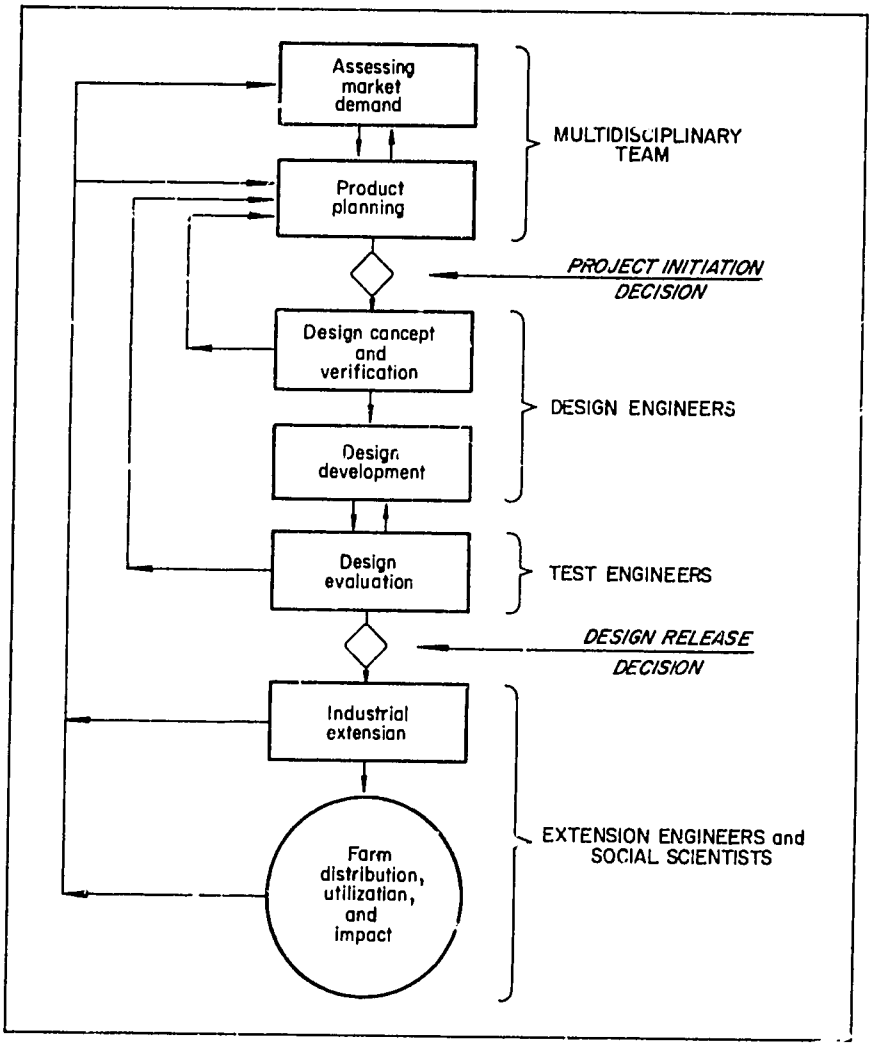
Table 1. Profile of respondents, Thailand and Philippines (22).

Item	Thailand			Philippines					
				Irrigated			Rainfed		
	Thresher owner	Thresher nonowner user	Thresher nonowner nonuser	Thresher owner	Thresher nonowner user	Thresher nonowner nonuser	Thresher owner user	Thresher nonowner user	Thresher nonowner nonuser
No. of respondents	63	156	49	18	26	21	5	16	15
Age (yr)	48	48	45	52	50	59	50	49	49
Education (yr)	4	4	4	6.3	4.7	5.0	5.1	6.7	5.4
Tenure (%)[a]									
Landowner	55/95	40/86	29/98	56	38	57	60	60	67
Landless	45/5	60/14	71/2	44	62	43	40	40	33
Av farm size (ha)	8.9	6.0	7.5	5.1	2.1	1.8	4.4	2.7	2.4
Av yield (t/ha)[b]	2.9	2.7	2.7	3.8	3.9	2.9	2.4	2.8	2.7

[a]Under Thailand, the first figure is for Chachoengsao Province, the second for Supanburi. [b]MVs: RD7, RD11 for Thailand; IR36, IR38, IR42 for the Philippines.

Public sector engineering R&D investments by national agencies and academic institutions in the Third World have a poor achievement record (4). In almost all cases, these efforts have been out of touch with the needs of end users (small farmers). Conversely, reliance on imported equipment from the developed countries is often both expensive and technically inappropriate to the requirements of small (2-5 ha) rice farmers. Also, before the 1960s, markets for farm equipment were severely limited by the low productivity levels and low investment potential of small farms. Beginning in the late 1960s, technologies that raised yields substantially improved the productivity of cost-saving, output-increasing devices.

Early proponents of the IRRI engineering program also asserted that the rapid spread of modern varieties —with attendant increases in yield — and expanded multiple cropping stressed available human and animal power resources. Against this background it was argued that use of mechanical power would complement existing land and water resources and supplement labor and animal power.



2. Design, development, testing, and extension system used by IRRI's small-farm equipment program.

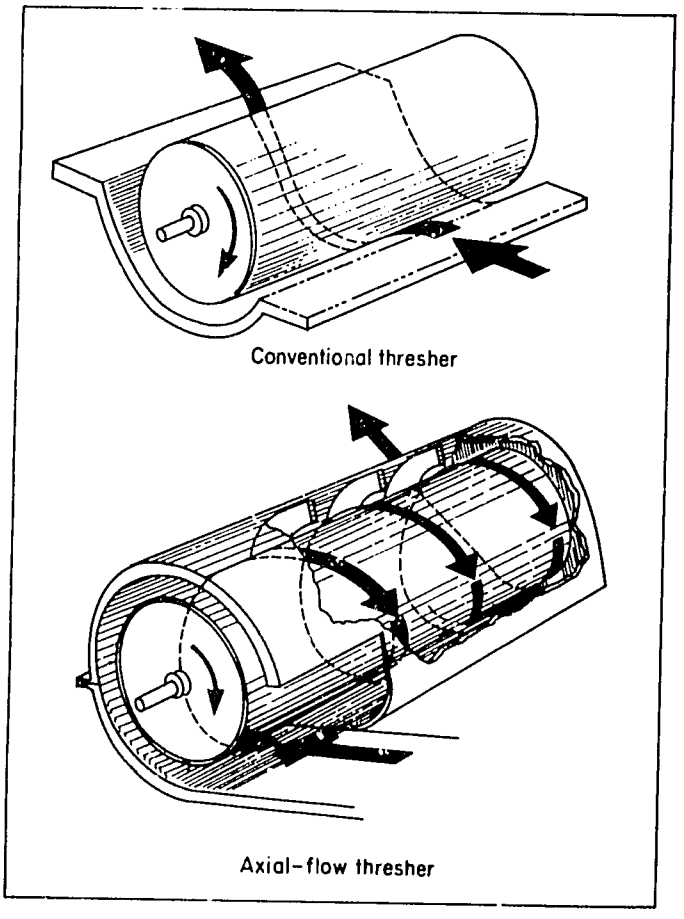
The objective of the IRRI program was to provide local manufacturers with technical support and equipment designs having strong commercial potential. The machines were designed to be fabricated using simple, labor-intensive techniques as well as local materials and labor, and to be operated and maintained with a minimum of training and mechanical infrastructure. Because of this commercial orientation, IRRI evolved over nearly 10 yr an operational procedure that included assessment of farmer needs and specification of product design parameters, followed by design, development, testing, and industrial extension (Fig. 2). IRRI's global mandate meant addressing a very wide range of technical and socioeconomic conditions, with the inherent danger of diluting the program's focus. At an early stage, therefore, a decision was made to design and develop the machinery for rice farmers who have the investment capability to use mechanical innovations profitably. Lowland, irrigated farms were the initial target market.

The program also included training of engineers from private firms and national agencies with whom IRRI collaborated in developing local extension programs. The ultimate goal was to institutionalize the design and development process in local agencies.[2] Major collaborative programs involving placement of personnel and commitment of significant funding resources were established in Bangladesh, Thailand, India, Egypt, Pakistan, Burma, Indonesia, and the Philippines.

[2]The process described briefly here closely parallels that enunciated by Hayami and Ruttan (15) in which technology transfer is described as a three-phase process. The first phase is a simple transfer of materials, e.g., tractors and combined harvesters, in which local industry plays little or no role except to assemble and service the machines. In the second phase, designs are transferred from one country to another as blueprints or prototypes. The third and most mature stage involves transfer, through development of human capital, of the capacity to design and develop technologies tailored specifically to localized needs. The IRRI program targeted the second and third stages of this process. In the short run, i.e., 10 yr, the program made available designs aimed at local markets and crafted to local manufacturing capabilities. The program operated through national institutions. Both short- and long-term training were combined with ongoing technical support at both the institutional and the individual firm level. Over a 10- to 20-yr span, the objective was to develop indigenous skills and institutionalize the capacity to continue and extend design and development activities.

The axial-flow thresher

Work on the design of threshing machines began at IRRI in 1967 (24). At the outset, development focused largely on conventional threshing concepts. In 1970, the investigation shifted to the axial-flow principle (Fig. 3), which offered two distinct advantages over the conventional concept: 1) the machine could handle wet materials effectively, and 2) the spiral movement of material along the axis of the threshing drum produced a vigorous threshing action with extended exposure and high separation efficiency. The concept also resulted in a compact mechanism requiring no complex parts or special materials (16). The axial-flow concept appears to have originated in Germany in the 19th century (33) and was further developed in Japan (Y. Kishida, 1985, pers. comm.). Variations on the principle have been used for rice milling and cleaning equipment for many years and have more recently been extensively adapted for large combine harvesters in the United States, Canada, Australia, and Western Europe.



3. Conventional and axial-flow threshing concepts.

A completed design was released to Filipino manufacturers in 1974. This was quickly modified and multiplied and, after a short period of debugging, rapidly became a major commercial product. The initial model had a capacity of about 1 t/h, was mounted on rubber tires, and was normally pulled to the threshing site by jeep or carabao (Fig. 4a). After a series of field studies in Central Luzon, the need was identified for a lighter, more mobile unit for easy access to interior fields, and a portable version (Fig. 4b, 4c) was developed (28, 42).

Since 1976, the basic design has remained essentially unchanged. Refinements have been incorporated to improve cleaning and separation efficiency, increase capacity (30), extend utility for threshing wheat and maize (24; Fig. 4d), and tailor manufacturing requirements to meet local capabilities (34). By 1985 more than 200 manufacturers in 18 countries had entered production following the axial-flow design.

DISSEMINATION AND ADOPTION

Production of the axial-flow thresher

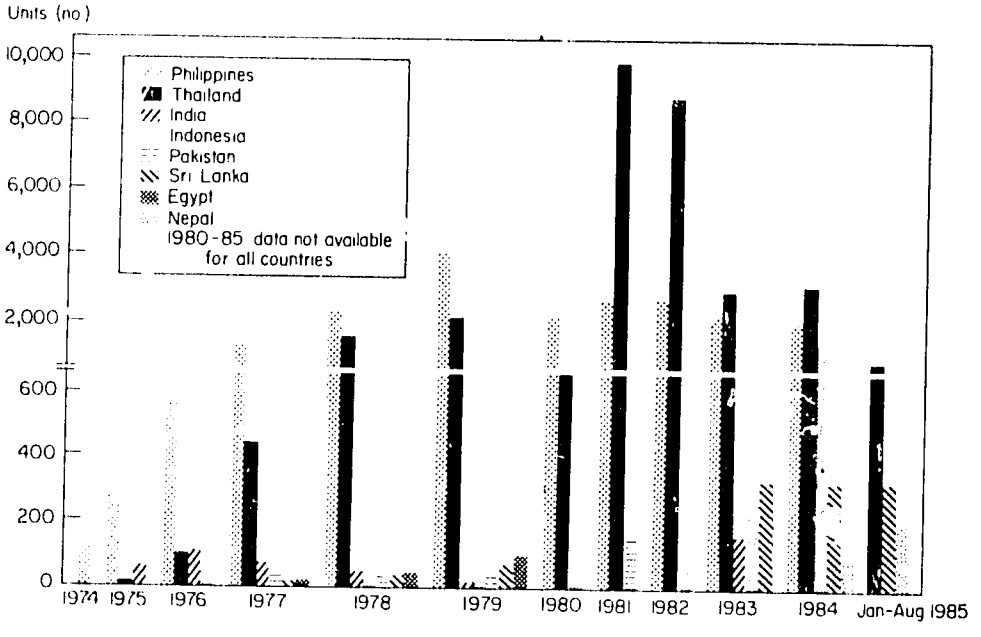
Statistics on the production and sale of the axial-flow thresher are incomplete. There are, however, data available from the IRRI extension network that enumerate the production and sale of threshers produced by cooperating manufacturers in some countries. The data underestimate the true volume sold, because several firms with no formal association with the IRRI program copied the design. This undercounting may be as high as 50% in the Philippines and Thailand. Information presented in Figure 5 illustrates the rapid takeoff of the design in the Philippines and, with a lag of about 1 yr, in Thailand. Sales rose steadily in these two countries until 1982, when world economic conditions dampened economic growth and raised inflation levels. Devaluation in both countries raised the cost of imported components. Despite the generally unfavorable investment climate, manufacturers in both countries continued to produce and farmers continued to buy the threshers in significant numbers in the mid-1980s. Fewer but significant numbers of the machines have also been sold in Egypt, Indonesia, Sri Lanka, Nepal, and India. Prototypes have been shipped to or produced in Honduras, Pakistan, the Ivory Coast, Ghana, Colombia, and Mexico. By 1984, about 55,000 units had been built by cooperating firms.

Adoption patterns

Manufacturers quickly recognized the profit potential of the axial-flow thresher. The design spread rapidly from a handful of firms in 1975 to more than 70 widely dispersed firms in the Philippines in 1985.[3] Fewer firms participated

[3] IRRI's policy was not to provide exclusive manufacturing rights to any firm. This arrangement allowed the Institute to minimize the risk that a viable product would not become commercialized because of management or marketing problems within a single firm. It also fostered competition among firms, which resulted in better quality and lower prices. Lastly, the policy helped initiate a process of innovation and a commitment to design and development within individual firms (29), which improved existing products and produced new ones.

4. Axial-flow threshers designed and developed at the International Rice Research Institute: a) large axial-flow thresher, b & c) portable axial-flow threshers, d) large axial-flow thresher converted for shelling maize.



5. Production of IRRI-designed axial-flow threshers by cooperating manufacturers in selected countries, 1974-85.

in the IRRI program in Thailand, but the 20 companies fabricating the thresher in 1985 were larger and had more highly developed marketing channels than their Filipino counterparts.

Philippines. Mechanical threshers were used in Central Luzon beginning in the 1920s (25). These machines, locally known as *tilyadoras*, were similar to the McCormick stationary thresher used in the United States at the turn of the century. The threshers were owned by large haciendas and used as a mechanism for consolidating the rice crop at harvest time. All tenants were required to thresh their crop with the machine, and the landlord extracted his share. The *tilyadora* was a heavy, cumbersome machine that required harvesting, consolidation, and stacking of the crop several weeks in advance of threshing. Labor requirements were high, and the recovery efficiency of the design was low. The machine also performed poorly when threshing wet rice.

With land reform in 1972, farmers in Central Luzon reverted to hand threshing, performed largely by hired and exchange labor (11). In other areas of the Philippines, rice threshing remained largely a manual operation, although a number of locally fabricated, small threshing machines were used in the Bicol and Mindanao regions as early as the 1960s. During the late 1960s and early 1970s, expansion of irrigation facilities coupled with widespread adoption of early maturing varieties increased double-cropping and raised yields. These changes also increased harvesting and threshing labor requirements, although less than proportionate to the increase in production.

Table 2 shows adoption patterns of the axial-flow thresher in Laguna Province. Yields doubled from 1965 to 1978. Per hectare labor for harvesting and threshing increased slightly until 1978, which, with increasing yields and a constant crop share, meant that labor productivity also increased. With the introduction of the large axial-flow threshers in 1975, labor inputs decreased in 1978 but returned to nearly prethresher levels in 1981.

Demand for axial-flow threshers in the Philippines is divided between the portable machine (found principally on Panay Island) and the larger version, which is widely used for contract work in Central Luzon and Laguna (Fig. 6). A few portable machines were acquired in Laguna, principally by individual farmers whose highest priority was threshing their own crops; contract work was a secondary consideration (5).

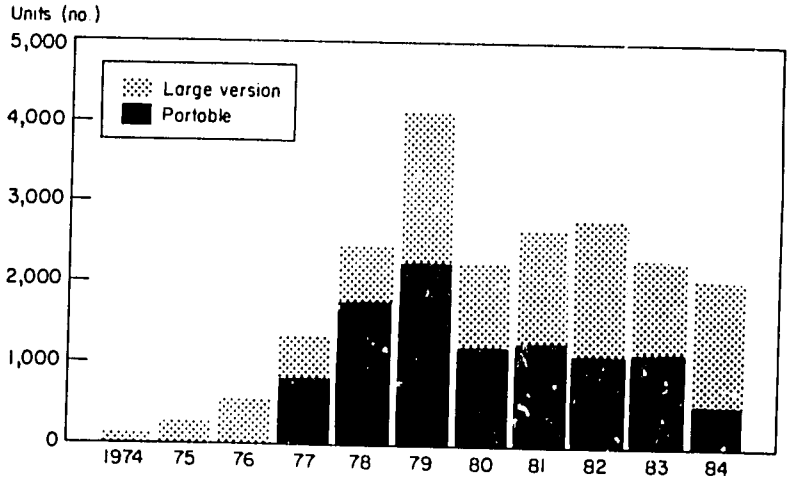
IRRI introduced the portable axial-flow thresher into Iloilo Province in 1976 (21). All threshing in the area had previously been by the traditional foot treading method. Introduction of improved varieties, followed by irrigation development, set the stage for the mechanical thresher (Fig. 7). Use of the new varieties in Iloilo increased both yields and incomes, thus raising the investment potential of farmers. Irrigation permitted double-cropping, which tightened the time constraint between crops and raised incomes further. As in Laguna, portable thresher owners in Iloilo were individual farmers whose first concern was use of the machines on their own farms.

In villages where machines were purchased, adoption rates were rapid and almost complete. Since 1978, off-farm use for contract services has also become important in Iloilo. Thresher owners in Iloilo, Laguna, and Central Luzon all used their machines for custom threshing operations (Fig. 8). Portable machines were used for contract work to a lesser degree than the larger units.

In the Philippines, almost all threshers were produced by a relatively large number of small firms selling in a very localized regional market. However, by the early 1980s, the major share of the market for larger axial-flow threshers was supplied by two or three firms.

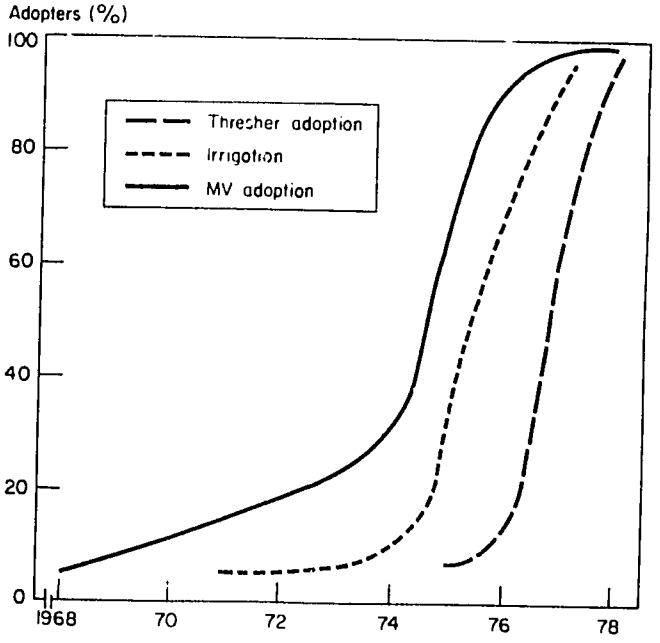
Table 2. Thresher adoption and labor use, Laguna Province, Philippines, 1965-78 (26).

Item	1965	1970	1975	1977	1978
Farmers using threshers (%)	0	0	0	67	82
Harvesting and threshing labor (d/ha)	30	32	32	26	31
Yield (t/ha)	2.2	3.1	3.4	3.7	4.6



6. Demand for IRRI-designed axial-flow threshers, Philippines, 1974-84.

Thailand. Introduced into Thailand in 1975, the axial-flow design was quickly adapted to local conditions by manufacturers who aggressively promoted the machine in irrigated rice areas (31). Farmer adoption was also rapid. The Thai market was exclusively for larger units, which were used almost entirely for contract work (27, 30). The smaller portable version was tried in 1977 but not accepted. Instead, manufacturers increased the size and capacity of the thresher until output capacity was three to four times that of the original design. Because almost all threshing is on a contract basis, improved mobility was also a major aim of the adaptation process. Today the threshing mechanism is often mounted on the chassis of a second-hand truck or car to permit transfer over appreciable distances.



7. Adoption of 3 rice production technologies in 3 sample irrigated villages, Iloilo. 1968-78 (20).

By 1975, farmers in Thailand had widely adopted 2- and 4-wheel tractors for land preparation, and low-lift pumps for supplemental irrigation (40). Spread of modern varieties (MVs) was limited, however, largely because of poor grain quality, a factor of great importance in the Thai export market. Also, rice farms in the Central Plain of Thailand were larger than their counterparts in the Philippines, and there was continued growth in the area under cultivation (3).

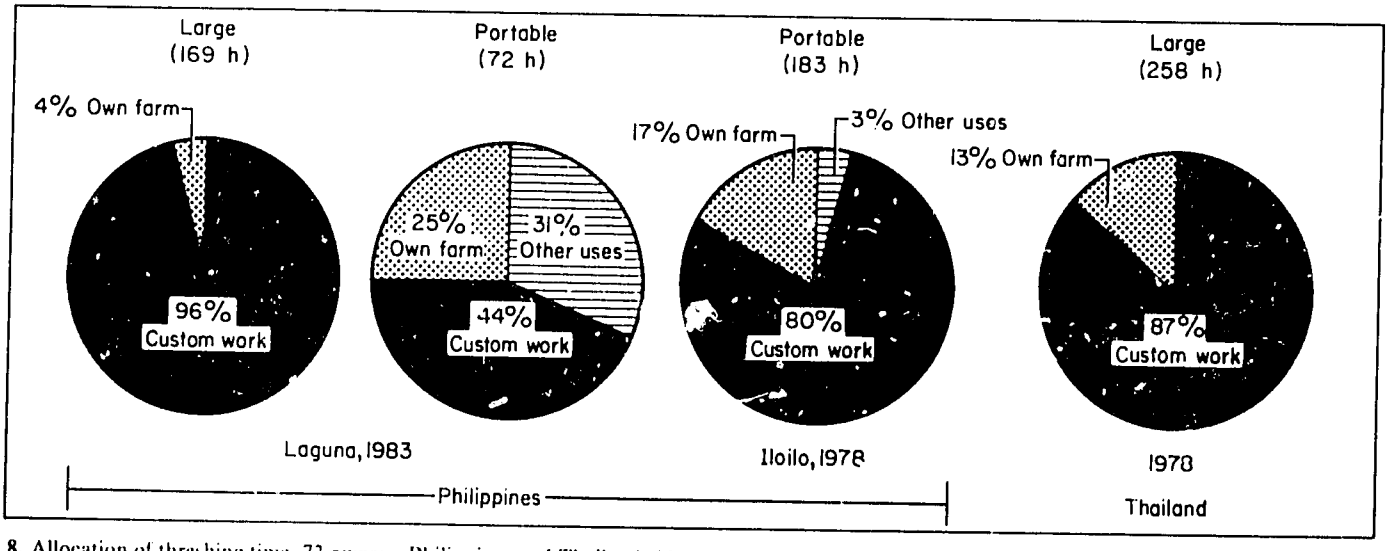
Ownership and use patterns

In both Thailand and the Philippines, ownership of a thresher was not a requirement for using it. Contract rental service has long been a feature of mechanical land preparation in both countries. Hence, many thresher owners bought the machines not only for own-farm use, but as a source of revenue.

Figure 8 presents the breakdown of thresher use between own-farm and contract services. For larger threshers, contract income was likely a decisive factor in the purchase of the machine. In both countries, the majority of the owners were farmers (Table 1), although 45% of the Thai threshers in Chachoengsao Province and 40% of the machines in the Philippine sample were owned by landless respondents, indicating a significant number owned by nonfarmers. Of the 92 thresher owners interviewed in the two countries, more than 70% had bought the machines with cash (Table 3). In rainfed areas, more

Table 3. Sources of funds for rice thresher investment (21, 22).

Source	Thailand	Philippines	
		Irrigated	Rainfed
Cash (%)	69	83	60
Loan (%)	7	–	–
Both cash and loan (%)	24	17	40

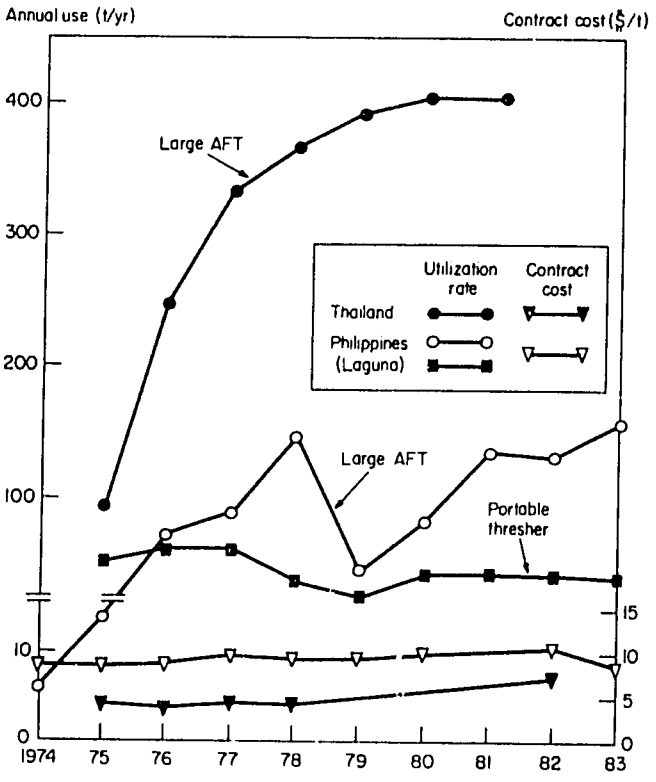


8. Allocation of threshing time, 73 owners, Philippines and Thailand, 1978 and 1983.

of the machines were purchased through formal and informal credit arrangements, but both yields and sizes of rainfed farms tended to be lower, suggesting a lower investment potential than irrigated farms. Credit was also a more important requirement for rainfed than for irrigated farms in the Philippines.

Use of threshers

Although data are not available to examine thresher use patterns precisely, a descriptive profile of both use and contract rates has been constructed from field studies (18, 31). Initially, with few threshers available and no demonstrated performance record, annual use levels were low (Fig. 9). Contract terms were on a cash basis of $3.8-$4.8/t in Thailand and 5-9% of the gross output threshed in the Philippines. Annual use levels for the large axial-flow thresher increased steadily in the Philippines except in 1978-79, when fuel prices rose significantly. Use levels for portable threshers remained nearly constant, confirming the earlier observation that portable machines are used primarily for threshing the farmer's own crop, with contract work as subsidiary consideration. Use of the smaller machines was also more localized at the village level, and owners did not solicit contracts over the wide areas covered by the larger threshers.



9. Annual use rates and contract costs for mechanical axial-flow threshers (AFT), Thailand and Philippines, 1974-83.

In Thailand, as machines increased in size, capacity, and mobility, annual use increased sharply. Contract rates have not changed appreciably since 1976.[4]

In both countries, the increasing stock of threshers has begun to dampen further increases in annual use. Competition for available threshing contracts has also mitigated further increases in the contract rate, even if the investment cost of the machine and fuel prices have more than doubled since 1975.

MECHANICAL THRESHERS AND LABOR

In developing countries, an important policy objective is to provide sufficient agricultural employment to absorb the growing number of people in the rural areas. Rapid adoption of threshing machines could critically affect employment opportunities for several reasons. Threshing is one of the most labor-intensive operations. Furthermore, it is usually carried out by hired laborers who belong to the poorest segment of rural society — landless and marginal farm households. Landless households are estimated as up to 20% of all rural households in the Philippines. In Thailand, they are too few to be considered significant by the government.

Payment for threshing has traditionally been as harvest shares. This enables landless laborers to participate to some extent in the benefits of yield increases accompanying the diffusion of new rice technology. The adoption of threshing machines could therefore seriously reduce the employment and earnings of landless laborers. On the other hand, threshers could theoretically have a positive effect on employment by reducing turnaround time and thereby increasing cropping intensity.

Field research in Thailand and the Philippines does not support the claim of higher cropping intensity or reduced turnaround time. Cropping intensity is primarily a function of irrigation and water control. Field studies by Juarez (18) show only a small intensity effect from mechanized threshing (Table 4). Although farmers using threshers complete their threshing earlier, they do not plant the following crop before others do in the same village. Time of planting is closely related to water availability and the need to synchronize crop establishment with others to minimize pest problems.

Manual harvesting and threshing require approximately 30 labor d/ha. The large axial-flow thresher performs both threshing and winnowing, and although about 4 labor d/ha are required to operate the machine, total labor requirements for postproduction operations fall to 20 d/ha, a decline of about 33% (41).

Results of surveys in Nueva Ecija, Philippines, showed that postproduction labor on mechanized farms was 25%

[4]Strictly speaking, the value of the contract has increased in both countries as yields increased. There is not, however, a direct relationship between yield and the time required to thresh a crop. Higher yields require less threshing time per ton of threshed output than low yields.

lower than on farms in which the rice was manually threshed (Table 5). Disaggregated into family and hired labor, the data reveal that the use of family labor was marginally higher on mechanized than on nonmechanized farms. Hired labor, which originates mainly from landless households, declined by 31%. This is consistent with the results of a multivariate regression analysis that revealed threshing mechanization as the most important factor accounting for between-farm differences in postproduction labor (37). Output had a positive impact on labor use. Its effect, however, was small compared with the effect of mechanization.

Farmers in both Thailand and the Philippines used a range of threshing methods. In Iloilo, foot treading from an elevated platform was the most prevalent. In Laguna, hand beating was done over a bamboo frame. In Thailand, grain was separated from straw by driving a water buffalo or a tractor over the crop. Winnowing was normally performed with a straw basket or wooden fanning mill.

Labor requirements for traditional methods differed markedly from those for mechanized threshing. The highest labor requirements and lowest labor productivity were exhibited by foot treading (Iloilo) and buffalo treading (Thailand). As shown in Table 6, use of the mechanical thresher increased labor productivity by a factor of two to four in Thailand and up to nine times in the Philippines.

On an aggregate basis, the mechanical thresher appears to have reduced the labor requirement for threshing by about 25% (39). For the Philippines, the impact appears to have been most sharply felt by the hired labor component. The evidence from Thailand is not clear. Less hired labor is used in the traditional threshing operations than in the Philippines, and the overall estimate is that mechanical threshers reduced *both* family and hired labor by a total of 10% (32).

Economy-wide employment impact

For the Philippines, Ahammed and Herdt (1) used a general equilibrium model with an input/output core to estimate the nationwide employment implications of increasing rice production using alternative production methods. If manual threshing were used to increase rice production by 1%, employment in the agricultural sector would increase by 16,000 labor yr. The employment effect would be 22% lower (12,400 labor yr) if portable threshers were used.

Ahammed and Herdt proceeded to estimate the impact of alternative threshing methods on nonagricultural employment by integrating backward and forward linkages. Domestically produced threshers would generate employment in the manufacturing sector. Increased rice output would have a positive effect on employment via consumption linkages. Taking all sectors into consideration, substitution of manual threshing by mechanized threshing would reduce the employment generating potential of increased rice production by about 7% (Table 7).

Although Ahammed and Herdt pointed out that ignoring nonagricultural sectors might result in overestimation of the labor-displacing effect of machines, it is important to bear in mind that the poorest segment of society lives in the rural areas.

Table 4. Impact of mechanized threshing on cropping intensity in rice-based systems, Philippines (18).

Area	Comparison	Cropping intensity effect
Iloilo (irrigated)	Foot treading vs power threshing	1.68 +13%
Iloilo (rainfed)	Foot treading vs power threshing	1.55 +4%
Laguna (irrigated)	Hand vs power threshing	1.43 +22%

Table 5. Hired and family labor use in postproduction activities, Central Luzon, Philippines, 1979-80 (39).

Item	Hired labor	Family labor (labor d/ha)	Total
Manual threshing	29.0	2.3	31.3
Mechanized threshing	20.1	2.9	23.0
Labor displaced	8.9	−0.6	8.3
Percent displaced	31.0	−5.0	26.0

Table 6. Labor requirements and labor productivity for rice threshing in Thailand and the Philippines (21).

Method	Time (labor d/t)	Amount (kg/labor d)
Thailand		
Buffalo treading	4.85	206
Tractor treading	2.40	415
Large axial-flow thresher	1.33	752
Philippines		
Foot treading	7.69	130
Hand beating	5.49	182
Portable axial-flow thresher	0.81	1230
Large axial-flow thresher	0.94	1070

Table 7. Employment implications (thousand labor yr) of a 1% increase in rice production using manual or mechanical threshing methods, Philippines (39).[a]

Method	Percent increase		
	Direct (agricultural sector)	Indirect (nonagricultural sectors)	Total
Manual threshing	15.9	27.1	43
Portable thresher	12.4	27.6	40
Difference (%)	22	2	7

[a]Adapted from Ahammed and Herdt (1).

Mode of payment

Payment for threshing has changed in both Thailand and the Philippines since the introduction of the thresher. In Thailand, wage payments to individuals have shifted to cash payments to thresher owners. Rates were $7.0-9.6/t for tractor or animal methods and $3.8-4.8/t when using a threshing machine. As noted earlier, the rate for machine threshing did not increase after 1980, largely as a result of an increased number of threshers vying for contract services.

In the Philippines, a more complex series of adjustments took place. Farmers using manual methods previously paid a combined share of the crop for harvesting, threshing, and cleaning — usually about 12-17%. With the introduction of the thresher, the share paid to threshing labor shifted to thresher owners and operators. The arrangements differed slightly among regions, but the normal fee was 8% of the crop. Under these rearrangements in sharing rates, labor received a smaller portion of total output. Combined with increases in the agricultural labor force and increasing ownership and operational costs for threshing equipment, there has been a decline in labor's share from 1/8 to 1/20 of the crop in some areas of Central Luzon.

Since the introduction of the machines, threshing fees have risen in the Philippines and have fallen slightly in Thailand. The crucial issue is how the introduction of threshing machines has affected threshing labor, particularly hired labor.

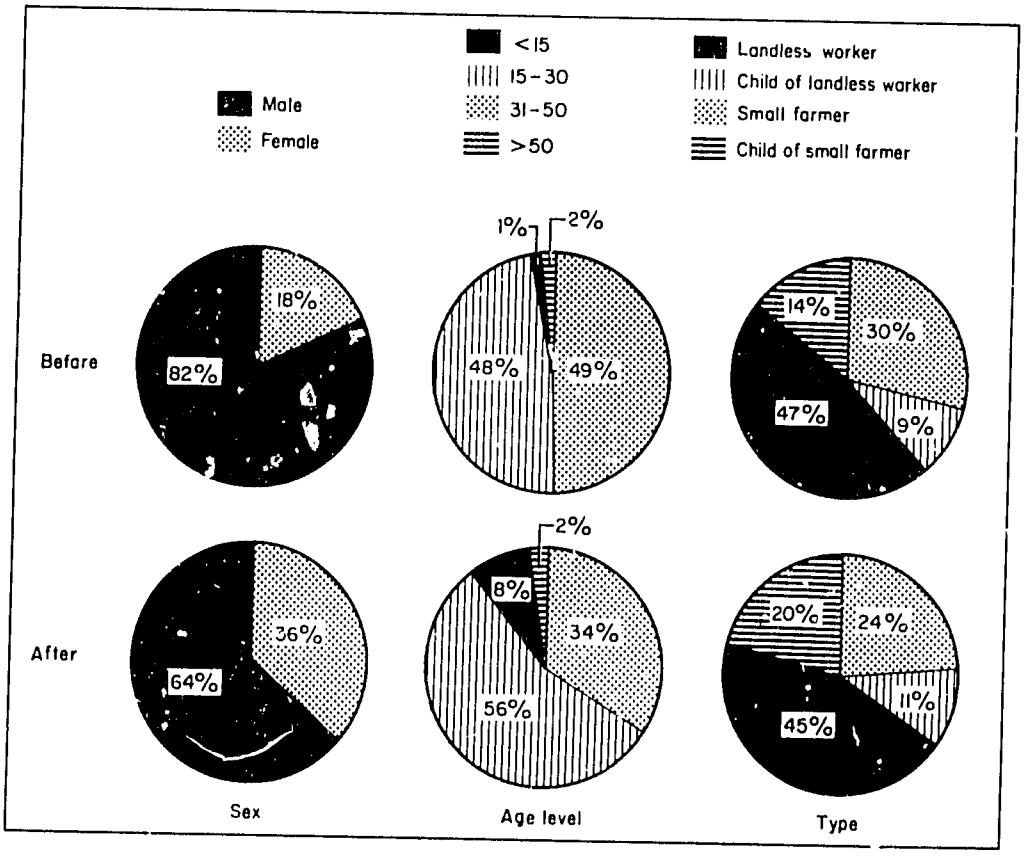
Landless labor

Most hired labor for postproduction operations in the Philippines comes from the landless class, estimated to be as high as 20% of total rural households in 1984 (12). Workers from the landless class contribute more than 50% of the labor used for harvesting and threshing. Add small farmers with less than 0.5 ha of land, and the level rises to more than 80%. Also, up to 80% of the annual income of landless workers and small farmers is derived from postproduction operations.

A study of landless workers carried out in a thresher-using area of Central Luzon revealed a number of nonincome benefits of threshers (11). Mechanized threshing considerably reduced the arduousness of postproduction operations. The lighter nature of the work also made it possible for more women and children to participate in more postproduction activities (Fig. 10). A majority of the laborers stated, however, that labor was in excess supply at harvest time, and they feared increased mechanization would further reduce earnings.

Wage rates

In countries with surplus agricultural labor, the introduction and utilization of machines normally exert a downward pressure on real wage rates. In the Philippines, the agricultural labor force is projected to grow at 1% per year (7), while in Thailand it has expanded at about 1.5% per year over the past 15 yr (3). In the Philippines, real wages in agriculture have been declining and were



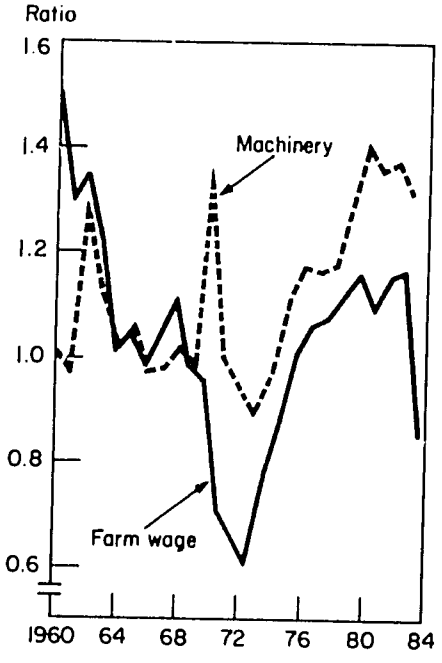
10. Changes in the composition of labor in harvesting and threshing, Philippines, 1983.

significantly lower in 1985 than during the mid-1960s. In the same interval, the real price of agricultural machines rose, with the largest increase occurring between 1972 and 1980 (Fig. 11). The failure of real wages to keep pace with growth in the agricultural labor force indicates that growth in employment opportunities in and outside agriculture has been less than growth in the agricultural labor force.

Evidence describing agricultural wages in Thailand shows that real wages increased steadily during the late 1960s and through the 1970s (Fig. 12). There was a decline during the early 1980s, when the global economic recession dampened growth. The upward trend appears, however, to have resumed in the mid-1980s.

For the Philippines, seasonality in agricultural wages cannot be ignored. A labor shortage at harvest time might coexist with a labor surplus during the rest of the year. Real wages for harvesting and threshing in Laguna increased before the introduction of the thresher, i.e., up to 1975, and labor demand at harvest time increased more rapidly than supply. The widespread adoption of mechanized threshing since 1978 was accompanied, however, by a steady decline in real wages, which in 1981 were below the level prevailing in 1975 (Table 8).

The decline in real wages for threshing in the Philippines should not, however, be tied too tightly to introduction of threshing machinery. Real wages also fell for other operations in the rice production system and in the industrial sector during this period. The implication drawn from an analysis of the wage data is that expansion in employment opportunities has not kept pace with the rapid increase in the agricultural labor force. In addition, while adoption of mechanized threshers may not be directly linked with the decline in real wages, substitution of capital for labor under a falling real wage clearly reduced the income in rice threshing of workers involved in postproduction activities.



11. Ratio of indices of prices of inputs (labor and machinery) to price of unmilled rice, Philippines, 1960-84 (8).

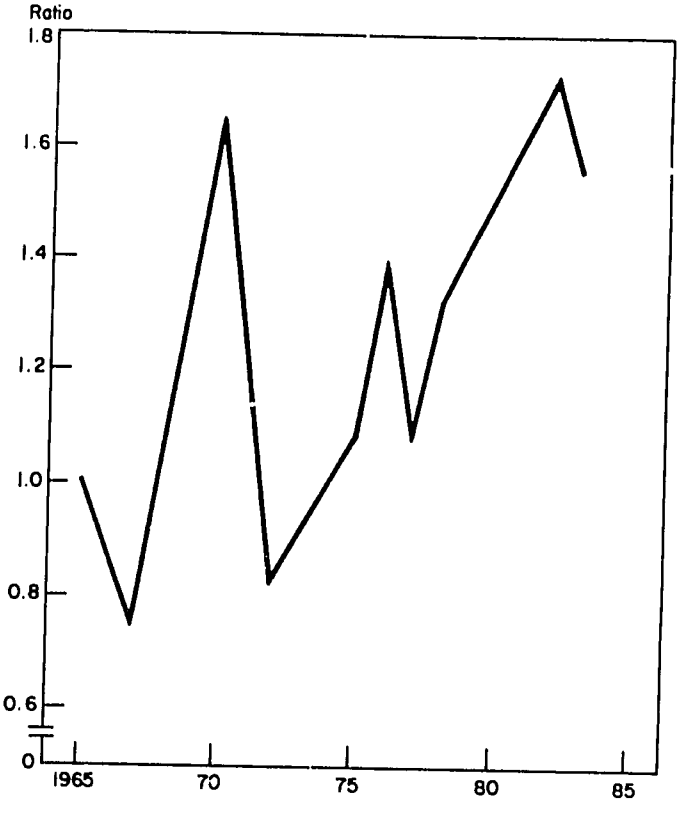
Income shares

Using the concept of factor shares, in which the total value of production is partitioned according to the contribution of individual production factors, it is possible to distinguish changes in the distribution of income of farms that used the thresher and of nonuser farms. In Laguna, use of the thresher reduced overall labor earnings

Table 8. Agricultural wage rates in rice production, Laguna, Philippines, 1965-81 (39).[a]

Item	1965	1970	1975	1978	1981
Harvesting and threshing					
Nominal wage[b] ($/d)	1.08	0.91	2.32	2.48	2.38
Real wage ($/d)	1.08	0.70	0.78	0.64	0.40
Index of real wage	100	101	140	113	79
Transplanting					
Index of real wage	100	121	104	83	85

[a]1US$ = ₱3.88 in 1965, ₱6.44 in 1970, ₱7.50 in 1975, ₱7.38 in 1978, and ₱8.20 in 1981. [b]Deflated by consumer price index outside Manila.



12. Ratio of labor wage to price of unmilled rice, Thailand, 1965-85 ([17] and interviews with agricultural engineering trainees, IRRI, 1976-85).

by 6% (Table 9). The share of earnings for unskilled (hired/landless) labor, however, declined from 33 to 23%. The major beneficiaries were capital and the farm operator.

In both Thailand and the Philippines, use of threshers reduced labor requirements significantly from traditional levels, but with a different impact on labor. In Thailand, with an expanding land frontier, a small landless worker class, and a rising real wage in agriculture, use of threshers was both economically efficient and timely. Total rice production increased at an annual rate of 3.8% during the 3 decades following 1955. About 75% of this increase resulted from an expansion in area under rice (2). During the same period, the available land per agricultural worker increased at almost 2%/yr. Under these circumstances, the introduction of threshers along with tractors and water pumps increased labor productivity, sustained increases in rice production, and had little or no inimical impact on the level or distribution of rural income.

In the Philippines, growth in rice output since 1967 has averaged about 4%, with almost 80% of the increase attributable to higher yields and the remainder to area expansion, primarily increases in irrigated land (2). While nominal wages have risen, the real wage in agriculture has fallen continuously since the 1960s. This has been paralleled by a fall in the land-labor ratio caused by an increase in agricultural labor force and little or no growth in cultivated area. Under these circumstances, use of mechanical threshers has limited increases in rural employment opportunities and decreased hired labor income. In a succeeding section, we review government policies that made adoption of threshing equipment attractive to owners and farmer-users despite falling real wages.

PRIVATE PROFITABILITY

The private profitability of the axial-flow thresher is examined from two perspectives. The first is that of the farmer who does not own but uses the thresher on a contract basis. In this instance, the reduction in cost and increased output from using the machine compared with traditional techniques determine the level of benefits. The second perspective is that of the machine owner. The contract rate, annual use level, investment cost, price of fuel, and price of rice determine the rate of return on investment in the thresher.

Yield effects

An important benefit of thresher use is that it enables the farmer to recover a higher proportion of the yield from the harvest. Theoretically, manual threshing could be equally thorough. In practice, however, laborers tend to terminate the threshing operation prematurely. Grain remaining with the straw is then appropriated by gleaners, usually elderly relatives or children of laborers. Gleaning is highly lucrative; diligent gleaners may appropriate up to 10% of the harvest (13). In this situation the thresher is a substitute for additional labor supervisors (38).

In addition to losses caused by laborers working without adequate supervision, the thresher has certain technical advantages over manual threshing. It reduces losses caused by repeated handling of both threshed and unthreshed materials. Winnowing and cleaning may be an integral part of the axial-flow thresher.[5] The effect of these factors has been meticulously measured in on-farm experiments comparing handling, threshing, and winnowing losses from manual and mechanized methods (Table 10). There is consistent evidence of a reduction in grain loss at all sites in the Philippines. The machine gave 0.5-1.6% losses or a net savings over traditional threshing of 0.7-6% of the total yield. In Thailand, the yield impact of reduced losses was insignificant compared with tractor and buffalo treading. Grain quality under the two techniques was also compared (42). The only significant differences when using the machine were a 2% decline in impurities and a slight increase in the percentage of fermented grain.

Table 9. Division of factor shares for rice farmers using and not using mechanical threshers, Laguna, 1983 (39).[a]

Item	Thresher renters		Nonusers	
	$/ha	%	$/ha	%
Land owner	87.86	17	87.86	18
Total labor[b]	139.63	27	160.03	33
Unskilled[c]	116.71	23	160.03	33
Skilled[d]	22.92	4	0	0
Capital	80.01	16	45.63	10
Current inputs	80.49	15	80.49	17
Operator's residual	127.49	25	104.16	22
Value of production	515.48		478.17	

[a]1US$ = ₱14.66. [b]Including gleaners at $16.85/ha. [c]Excluding thresher operators. [d]Thresher operators.

Contract services

Farmers renting threshers are concerned with the comparative costs of traditional versus mechanical methods. Other reasons frequently cited for using the machines included lower losses (in the Philippines), less supervision of labor, less handling prior to threshing, and quicker completion of threshing. Of these, only the yield effects and contract rates are included in the analysis of financial returns to thresher users.

[5]Several versions of the thresher exist. In the larger models, threshing, cleaning, and winnowing are standard features. In the portable models, the cleaning and winnowing mechanisms may be added as options.

Table 10. Yield effect of axial-flow threshers, Philippines and Thailand.

Area	Reference	Threshing method	Physical grain loss (% of yield)	Grain savings (% of yield)
Central Luzon, Philippines	(41)	Axial-flow thresher	1.10	
		Threshing frame	2.40	+ 1.30
Bicol, Philippines	(41)	Axial-flow thresher	0.48	
		Threshing frame	1.56	+ 1.08
		Flail or stick	1.20	+ 0.72
Laguna, Philippines	(18, 21)	Axial-flow thresher	1.60	
		Hand beating	7.34	+ 5.74
		Portable axial-flow thresher	1.34	
		Hand beating	7.34	+ 6.00
Iloilo, Philippines	(18, 21)	Portable axial-flow thresher	1.34	
		Foot treading	1.65	+ 0.31
Supanburi, Thailand	(21)	Axial-flow thresher	1.66	
		Animal treading	1.12	– 0.54
Chachoengsao, Thailand	(21)	Axial-flow thresher	1.66	
		Tractor threshing	0.97	– 0.69

Table 11. Harvesting and threshing[a] contract rates in the Philippines (% gross output) and Thailand ($/t), 1978 and 1983 (19, 21).

Location	Traditional harvesting and threshing			Traditional harvesting and mechanical threshing		
	Total shares	Harvester share	Thresher share	Total shares	Harvester share	Machine share[b]
Philippines						
Laguna, 1978	12.5	6.9	5.6	17.0	10.0	7.0
Laguna, 1983	12.5	6.9	5.6	19.0	10.0	9.0
Iloilo, 1978	16.6	11.1	5.5	16.6	11.1	5.5
Iloilo, 1983	16.6	11.1	5.5	16.6	11.1	5.5
Nueva Ecija, 1983	14.2	–	–	15.6	9.1	6.5
Thailand						
Chachoengsao, 1978		6.9 (tractor treading)				3.8
Supanburi, 1978		7.5 (tractor treading)				4.8
		9.6 (buffalo treading)				

[a]Traditional threshing refers to hand beating in the Philippines and to tractor and buffalo treading in Thailand. [b]Machine share includes charges for fuel, oil, grease, operators, and the machine itself. In both countries about 33-40% of the machine share is paid to operators and helpers and the remainder accrues to the machine owner, who pays for fuel, oil, and grease. In most cases, the charge for the machine includes cleaning of the grain. The large axial-flow thresher has a built-in cleaning mechanism and accomplishes this task as an integral part of the threshing operation.

Table 11 lists harvesting and threshing contract rates in the Philippines and Thailand. In the Philippines, sharing rates for both traditional methods and machines did not change in Iloilo between 1978 and 1983. In Laguna, rates for machine threshing increased from 7 to 9%, and manual threshing was virtually eliminated.

Of particular interest are the *increases* in total shares for all combinations of harvesting *and* mechanical threshing in Laguna, Iloilo, and Nueva Ecija. Farmers using threshing machines continued to pay labor at or above the traditional rate for cutting and hauling the crop (harvesting). In Laguna, the harvester's share increased from 6.9 to 10% and threshing cost rose from 5.6 to 7% in 1978 and to 9% in 1983. Comparing traditional and mechanized threshing, there was an overall increase in the total harvesting/threshing share from 12.5 to 17% in 1978 and from 12.5 to 19% in 1983. No similar changes in sharing arrangements were observed in Iloilo, and only a difference existed between traditional and mechanized systems in Nueva Ecija.

Part of the explanation for Laguna farmers' acceptance of higher postproduction costs lies in the increased output obtainable using the thresher. A second reason not explicitly obvious in Table 11 is the rapid urbanization over the past decade of Laguna, which is close to Metropolitan Manila. By 1985, almost all traditional threshing had disappeared in Laguna as workers moved to jobs in nonagricultural industries.

Charges for traditional threshing techniques tend to be higher than machine rates in Thailand. The major difference in the financial profitability of the thresher between the two countries is that Thai farmers benefited from the reduced costs of machine threshing compared with traditional methods, while Filipino farmers had the added advantage of a reduction in grain losses.

Thai farmers using the axial-flow thresher were able to increase revenues by $2.84/t compared with traditional methods, or $62/farm per season (Table 12).

Table 12. User benefits from axial-flow threshers compared with traditional methods, Thailand and the Philippines, 1978 and 1983 (21, 22).

Location	Cost savings over traditional method[a] ($/t)	Value of grain losses saved ($/t)	Total mean gain		
			$/t	$/ha	$/farm[b]
Thailand, 1978					
Large thresher vs tractor/buffalo treading	3.55	-0.71	2.84	17.0	62.0
Philippines, 1978					
Large thresher vs hand beating (Laguna)	-1.84	7.63	5.79	26.0	113.0
Portable thresher vs foot treading (Iloilo)	2.36	0.38	2.74	9.1	23.0
Philippines, 1983					
Large thresher vs hand beating (Laguna)	-3.36	5.68	2.32	10.4	45.2
Portable thresher vs foot treading (Iloilo)	1.92	0.31	2.23	7.6	19.2

[a]Includes savings from exclusion of meals, which are normally a part of traditional threshing methods. [b]Includes only farms growing MVs.

Table 13. Financial analysis of large and portable mechanical thresher investment in Thailand and the Philippines, 1978 and 1983.

Item	Thailand 1978 Large	Philippines					
		Iloilo, 1978		Laguna, 1978		Laguna, 1983	
		Portable (Irrigated)	Portable (Rainfed)	Large	Portable	Large	Portable
Initial cost ($)	1699.00	748.00	789.00	2136.00	837.00	1569.00	546.00
Fixed costs ($/yr)							
Depreciation	250.35	134.64	142.02	320.40	150.66	235.35	98.28
Interest	110.15	49.37	52.07	140.98	55.24	129.44	45.04
Repair and maintenance	166.90	74.80	78.90	213.60	83.70	156.90	54.60
Tax and insurance	33.38	14.96	15.78	42.72	16.74	31.38	10.92
Total fixed costs	560.78	273.77	288.77	717.70	306.34	553.07	208.84
Variable costs ($/t)							
Fuel	0.14	0.63	0.63	0.87	0.50	0.83	0.75
Oil	0.06	0.04	0.04	0.07	0.03	0.03	0.04
Grease	0.01	0.00	0.00	0.01	0.00	0.01	0.00
Labor	1.56	2.20	2.20	3.74	3.74	3.56	3.56
Total variable costs	1.77	2.87	2.87	4.69	4.27	4.43	4.35
Contract rate ($/t)	4.27	6.72	6.72	9.31	9.31	8.90	8.90
Annual use (t)							
Average	366.90	145.00	75.00	149.00	39.00	155.20	37.60
High	377.00	162.60	75.00	175.00	60.00	186.80	62.70
Break-even point (t/yr)	224.31	71.13	75.01	155.35	60.78	123.73	45.90
Payback period (yr)							
Av annual use	2.75	1.79	5.56	7.34	20.47	4.17	9.02
High annual use	2.64	1.54	5.56	5.19	5.70	8.03	3.12
Benefit-cost ratio							
Av annual use	1.26	1.38	0.95	0.06	0.75	1.08	0.88
High annual use	1.28	1.45	0.95	1.04	0.97	1.18	1.13

In the Philippines, the total cost of harvesting and machine threshing was higher in Laguna and lower in Iloilo than traditional methods. The cost of machine threshing increased from 1978 to 1983 in both regions. Despite higher costs, farmers renting the machine realized an increase in revenue of $2.23-5.79/t because of increased grain yields or reduced costs. The advantage over traditional threshing narrowed slightly in 1983 in Laguna, when contract rates for machines increased from 7 to 9%.

Thresher owners

For thresher owners, private profitability is determined not only by the contract rate, but also by annual amortization charges and operational costs plus the level of use. Table 13 summarizes the information on axial-flow thresher cost and use patterns for Thailand and the Philippines.

In Thailand, machines threshed nearly 3 times as much grain per year as similar units in the Philippines. Despite

higher initial investment costs and lower contract charges, these machines had a very short payback period and a high benefit-cost ratio (BCR). The evidence presented in Figure 9 indicates that annual use levels began to level off at about 400 t/yr. In the future, as more threshers enter the contract market, the high degree of profitability evident in the present analysis will likely decline.

Thresher owners in the Philippines had lower use levels, resulting in longer payback periods and lower BCRs than found in Thailand. Portable threshers in Laguna showed very low returns in 1978. This observation was made, however, shortly after introduction, when use levels were low. Both the portable and large machines operating in Laguna showed improved financial performance in 1983. Portable threshers operating in irrigated areas in Iloilo gave very high returns in 1978, although machines in rainfed areas were not as attractive, primarily because of low annual use levels.

The comparative performance of threshers in the two countries is summarized in Figure 13. While not shown in the figure for Thailand, breakeven levels increased after 1978 as machines became larger and initial investment costs increased (30). For the Philippines, average annual use levels were sufficient to ensure profitability, although financial performance differed by region and by machine type. Threshers in Thailand were better investments than those in the Philippines, with the exception of irrigated farms in Iloilo.

It is clear from this analysis of empirical use and cost data that axial-flow threshers were profitable from both a user's and an owner's point of view. This profitability was a major factor in inducing the widespread sale of threshers and a rapid expansion in the stock of machines in each country. In the next section, we examine whether government policies effected the rapid diffusion of threshers.

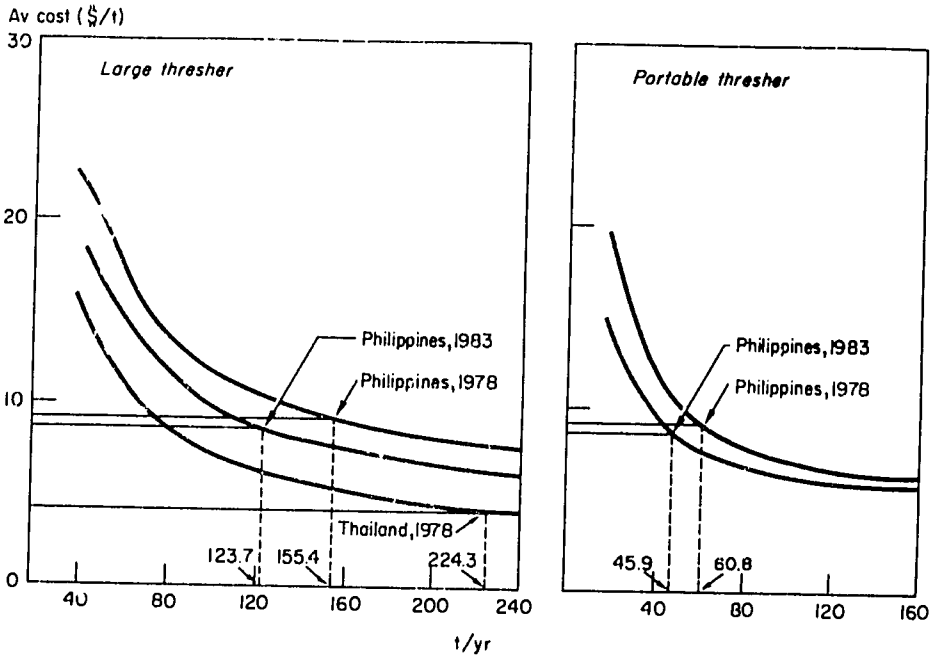
PUBLIC SECTOR INTERVENTION

That the mechanization of rice threshing is privately profitable in both Thailand and the Philippines is supported by the rapid growth rate in the adoption of IRRI threshing technology. We may now ask: Do government policies and programs make mechanization artificially profitable? If so, which policies?

Table 14 lists the range of policies associated with farm mechanization that are currently active in the Philippines and Thailand. In both countries, there is little evidence of direct government intervention affecting decisions to develop, purchase, or adopt rice threshers or most other forms of agricultural mechanization. In neither country is there a clearly articulated policy relating to technology design or transfer of farm equipment.

While there exist few specific policies to promote mechanization in general or rice threshing in particular, the government is influential indirectly, through policies affecting trade, exchange rates, credit, and interest rates. Price supports for rice in the Philippines and levees in Thailand also indirectly affect the profitability of mechanization. Each of these policies influences the relative costs of capital and labor.

In the Philippines, the World Bank has provided a series of four credit lines since 1965, totalling US$76 million (36). These loans, however, have benefited primarily those purchasing 4-wheel tractors (Table 15) used in both sugar and rice production. To a lesser degree, imported 2-wheel walking tractors suitable for rice cultivation were also financed during the early years of the program. Beginning in 1975, however, most 2-wheel units were made locally and purchased with farmers' funds. Very few rice threshers were acquired through formal financing arrangements (18). Data in Table 15 also show



13. Break-even levels for mechanical thresher investments, Thailand and Philippines, 1978 and 1983.

Table 14. Summary of policy and institutional programs affecting development and extension of farm machinery in the Philippines and Thailand (7, 35, 36).

Policy instrument	Philippines	Thailand
Tariffs		
Assembled or completely knocked down agricultural machines	Engines, sprayers, 4-wheel tractor, harvesting-threshing machinery = 10% Hand tractor = 30%	Imported unit and/or engine = 33%
Components and spare parts	30%	Internal parts = 15% Roller chain and steel = 25% Rubber parts = 50%
Quotas	No import restriction	Import restriction at 5,337 units for second-hand 2-wheel tractors and 705 4-wheel tractors
Taxes	10% advance sales tax	3% business tax 11% profit tax 10% local tax
Credit programs	Available for each food crop; Central Bank/IBRD provided 4 credit lines amounting to $76 million from 1965 to 1984.	Direct installment distributors; Bank for Agriculture and Agricultural Cooperatives gives credit through fabricators and distributors
Manufacturing support programs	Board of Investments Agricultural Investment Incentives Act; rural artisans training courses; machine drawings and technical assistance provided by Ministry of Agriculture and Food and by IRRI Project; Agricultural and Distributors Association	Domestic production of small engines of less than 30 hp; technical assistance provided by FAO/UNDP Agricultural Mechanization Project with Agricultural Engineering Division; technical information published quarterly in News Digest; Thai-IRRI Industrial Extension Project; Agricultural Machinery Manufacturers Association
R & D programs	Agricultural Mechanization Inter-Agency Committee directs mechanization development activities; Agricultural Mechanization Development Program (AMDP) designs and develops machines and sets quality and safety standards; Agricultural Mechanization Test and Evaluation Center tests and evaluates locally manufactured machines; IRRI Agricultural Machinery Development Program; AMDP and IRRI study effects of mechanization.	Agricultural Engineering Division, Ministry of Agriculture coordinates nationwide surveys of agricultural machinery industry and socioeconomic studies; Regional Network for Agricultural Machinery provides technical assistance and conducts research in coordination with Ministry of Agriculture, cooperatives, and universities.
Income tax incentive	Inventors Incentive Act (PD1423) provides a 5-yr tax holiday	none
Exchange rate	₱18.43=US$1 (floating rate since October 1984)	Baht 27.37=US$1 (floating rate since 1983)

Table 15. Distribution (%) of Central Bank/IBRD grants for farm machinery as of 30 June 1980.

Item	% distribution									
	First (1965-68)		Second (1969-73)		Third (1974-77)		Fourth (1977)		Total	
	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
4-wheel tractors	86.8[a]	93.9[a]	56.5	85.2	56.8	86.2	29.6	65.2	87.4[a]	92.9[a]
Power tillers			31.4	11.4	34.6	11.8	51.8	17.9		
Irrigation systems and wells, and distribution works	11.6	4.9	10.6	2.7	6.8	1.3	1.7	0.6	7.8	1.5
Sprayers, grain dryers, threshers, and other farm machinery	1.6	1.2	1.5	0.7	1.8	0.7	2.0	1.4	1.7	0.9
Rice mills	–	–	–	–	–	–	14.9	14.9	3.1	4.7

[a]Four-wheel tractors and power tillers. Source: SGV and Co. and U.P. Business Research Foundation, cited in Reyes and Agabin (36).

that less than 2% of the World Bank credit resources were used for postproduction equipment.

In Thailand, the government has taken a generally laissez faire attitude toward small farm mechanization. There have been no formal credit programs to finance rice threshers, although most dealers provide installment credit to purchasers at commercial rates (6). Thai farmers also utilize commercial bank credit more often than Filipino farmers for purchasing threshers (Table 16). Farmers in the Philippines use more informal credit facilities or finance the machines more from private resources than do thresher owners in Thailand.

Table 16. Sources of loans for rice thresher investment (21, 22).

Source	Thailand		Philippines	
	Threshers (%)	Interest rate (%/yr)	Threshers (%)	Interest rate (%/yr)
Bank	74	12	17	12
Agricultural cooperative	16	15	–	–
Private moneylender	5	20-30	33	25-80
Relative	5	0	17	0
Not specified	–	–	33	–

PUBLIC INVESTMENT IN ENGINEERING RESEARCH AND DEVELOPMENT

The axial-flow thresher design was the result of development activities conducted by IRRI. The transfer of this technology has been strongly supported by the extension and training activities of the Institute. From IRRI's point of view, was the investment of public funds in the development and promotion of this design a viable and efficient use of resources?[6]

To correctly assess the overall costs and benefits of the thresher, a detailed summation of all costs associated with development and extension of the design and a measure of the net benefits from use of the machine at the farm level are required. As the assessment of the private profitability of the thresher indicates, it is difficult to obtain a clear and unambiguous measure of farm-level benefits. This is compounded by the major differences that exist in the use of the machine among regions and countries and the lack of field data to quantify this information.

To simplify the analysis of benefits, attention is moved back in the marketing chain to the manufacturer. Statistics have been maintained since the inception of the thresher development program in 1967 that catalog the manufacturers participating in the IRRI Industrial Extension Program and the number of machines sold each year. But these figures clearly understate the number of threshers produced because a large number of firms that are not formally associated with the IRRI project have freely copied the design from participating firms. In Thailand and the Philippines, failure to enumerate these firms will likely result in an underestimate of up to 50% in machines sold. In 1984, 79 manufacturers in the Philippines and 30 in Thailand were official participants in the IRRI-sponsored technology transfer program. Because of the high degree of uncertainty regarding prices created by lack of information about the mix of portable and large axial-flow threshers in each country, we have arbitrarily assigned a value of US$1000 as the selling price for each machine. This is a conservative estimate; most machines sold in Thailand are larger models with investment costs of up to US$2500 each. Local currency prices have changed over time as inflation and devaluation increased the cost of imported manufacturing inputs. Price changes expressed in local currencies have, however, been much more volatile than their dollar equivalents. Also, as more firms entered production of the thresher, competition kept prices from rising as rapidly as inflation.

To determine the costs of the thresher development and extension program, total expenditures from IRRI's central and special project budgets for 1967-84 were assembled (Table 17). These expenditures were further refined into those estimated to have been used to support thresher development activities. Reports detailing the work of the Agricultural Engineeering program over this period indicated that more than 50 identifiable projects were initiated in areas ranging from irrigation to rice milling. Clearly, threshers were not the only technology under development. During 1967-75, thresher development absorbed a significant share of staff time and resources. From 1975 until the early 1980s, transfer and commercialization of the design through training programs and formal industrial extension activities in the Philippines, Pakistan, Thailand, Indonesia, Burma, Egypt, and India required a sustained level of funding support. Since 1980, a smaller commitment has been required, primarily to further refine the design and to extend its utility to crops such as wheat and maize. While the exact magnitude of the expenditures can be questioned, the numbers reflect a reasonable estimate of the funding commitment to the thresher development program.

Both expenditures and sales are discounted to reflect their current value. From these, an aggregate BCR is obtained (Table 18). To test the sensitivity of the analysis to changes in the discount rate, the discount rate was

[6]Using the concept of domestic resource cost (DRC), which is based on the calculation of implicit tariffs and subsidies, the mechanical thresher was shown to have a lower DRC than traditional threshing methods. This means that fewer resources must be spent using the machine to generate a unit of foreign exchange than using traditional techniques. The analysis by Smith and Duff (39) indicates only a marginal advantage over manual threshing in the Philippines, while a similar assessment for Thailand demonstrates a very clear advantage for the machine when evaluated using social opportunity costs (31).

Table 17. Design, development, and extension costs; production; and value of IRRI axial-flow thresher, 1967-84.

Year	Research and development[a] (labor-yr)	Funding (thousand $)			Thresher project			Thresher production		
		Core	Project	Total[b]	% share[c]	Cost (thousand $)	Cumulative cost (thousand $)	No.[d]	Value[e] (thousand $)	Cumulative value (thousand $)
1966	7	23	36	59	0	–	–	–	–	–
1967	9	18	87	105	10	10.5	10.5	–	–	–
1968	14	15	123	138	15	20.7	31.2	–	–	–
1969	10	21	88	109	25	27.2	58.4	–	–	–
1970	14	29	105	134	30	40.2	98.6	–	–	–
1971	19	32	173	205	30	61.5	160.1	–	–	–
1972	17	28	235	263	40	105.2	265.3	–	–	–
1973	20	40	214	254	40	101.6	366.9	–	–	–
1974	21	49	274	323	40	129.2	496.1	120	120	120
1975	23	273	81	354	40	141.6	637.7	347	347	467
1976	27	340	330	670	25	167.5	805.2	798	798	1,265
1977	33	432	450	882	20	176.4	981.6	1,875	1,875	3,140
1978	34	486	242	728	15	109.2	1,090.8	4,228	4,228	7,368
1979	35	545	264	809	10	80.9	1,171.7	6,533	6,533	13,901
1980	36	643	268	911	5	45.5	1,217.3	2,952	2,952	16,853
1981	38	675	539	1,214	5	60.7	1,278.0	12,692	12,692	29,545
1982	41	739	543	1,282	5	64.1	1,342.1	12,221	12,221	41,766
1983	35	684	520	1,204	5	60.2	1,402.3	6,501	6,501	48,267
1984	35	630	736	1,366	5	68.3	1,470.6	7,251	7,251	55,518

[a]Total senior and support staff in IRRI small-scale machinery design and development program. [b]Total from both recurring budget commitments and from special projects. [c]Estimates based on semi-annual progress reports of the IRRI Agricultural Engineering Department. [d]Estimates based on statistics compiled by the IRRI Agricultural Economics Department and the Industrial Extension Program. [e]Each unit has been valued at US$1000.

Table 18. Estimated discounted benefit-cost ratios at alternative discount rates (DR) from resource investments in development and extension of the IRRI axial-flow thresher.[a]

Period	12% DR	20% DR	30% DR	40% DR
1967-75	0.6	0.5	0.4	0.3
1976-80	24.8	22.9	20.8	18.4
1981-84	125.0	162.1	165.5	168.9
Overall (1967-84)	20.4	11.9	7.6	4.4
Overall internal rate of return from 1966-84:		57.6%		

[a]Developed from data in Table 17.

increased from 12 to 20%. On an aggregate basis, it is clear the BCRs for thresher development were very high, from 20.4 with a 12% discount rate to 11.9 at 20%.

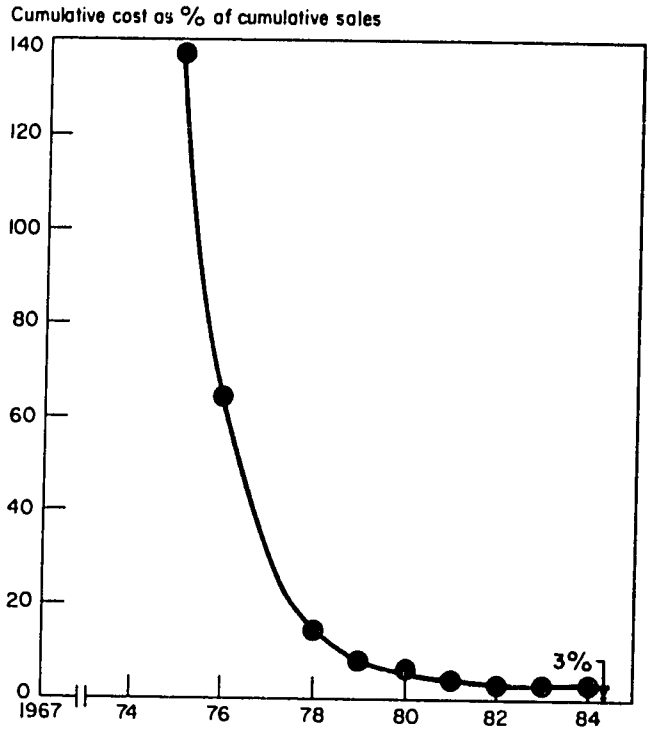
Calculations were also made to examine the time profile of returns to thresher development. During the first 10 yr, the BCRs were less than one. Only in 1975, after extensive extension and widespread fabrication by manufacturers and adoption by farmers, did the design become profitable.

Internal rate of return (IRR) calculations were also carried out to allow comparison of returns to engineering developments with other research activities at IRRI. Returns to engineering development compare favorably with investments in biological research, estimated to be between 80 and 100% (9). From a private sector viewpoint, an outlay of less than 3% of total revenues for research and development costs with an IRR greater than 50% is very acceptable (Fig. 14).

An important lesson from this admittedly simple analysis is the need for long-term commitments to effectively develop new engineering inputs. Had the IRRI program been terminated anytime during the first 10 yr, it is doubtful that there would have been a positive return on the resources committed to development of a new thresher. In addition, the analysis indirectly reveals the importance of a proper blend of development *and* technology transfer elements to achieve success. The transfer component did not become a significant factor until 1974, when special project funding was obtained to permit posting of IRRI engineering staff outside the Philippines. Without this commitment to an intensive extension effort, the spread of the thresher would have been largely limited to the Philippines, and its impact sharply reduced.

Thus, from a private (commercial) perspective, the sustained allocation of funding to thresher development produced clear positive benefits. Also, given the limited social cost analysis carried out by Smith (38) and Sukharomana (40), it appears that if the total impact of the costs and benefits from use of the thresher were quantified, the design would also produce a net social benefit in both Thailand and the Philippines.

IRRI's provision of *free innovation* lowers the price of machinery relative to labor. If private manufacturers had shouldered the development costs, these would undoubtedly have been passed on to the consumer in the form of higher market prices for threshers. This may have reduced or even eliminated its competitive edge over traditional threshing. Given each country's tariff structure, it is highly unlikely that private manufacturers would have been willing to invest resources in the development of the thresher. Even after the latest tariff reforms in the



14. Value of cumulative design, development, and extension costs for axial-flow threshers as a percentage of cumulative sales value, 1967-84.

Philippines, the effective protection rate on agricultural machinery (13.7%) is low relative to those on motor vehicles (27%) and consumer goods (43%). This diverts scarce capital resources away from machinery development toward import substitution in consumer goods and automobiles.

This effect is reinforced by poor enforcement of patents in each country. In addition, the design, although costly to develop, is in fact extremely simple and therefore easy to copy. This makes it difficult for private entrepreneurs to capture the gains from innovation.

At a time when the labor absorptive performance of domestic manufacturing has been disappointing and labor demand from the Middle East is approaching the saturation point, should IRRI be developing machinery that reduces labor demand in the agricultural sector? This question cannot be answered until the efficiency and equity effects of threshers have been more accurately quantified. Furthermore, IRRI's machinery development program is globally oriented — toward rice-growing areas in general and not toward conditions prevailing in particular countries. Even within Southeast Asia, socioeconomic conditions vary markedly from country to country. In Thailand, where the percentage of landless households is negligible, the efficiency/equity conflict is far less serious than in the Philippines, as the labor displaced in Thailand comes from farming households that benefit from the greater efficiency of mechanized threshing.

Under a laissez faire policy, the theory of induced innovation predicts that machinery development will arise, without government intervention, when relative factor price ratios are sufficiently favorable to capital. Under these conditions few equity problems arise. Overall, however, it appears that government support of labor-displacing machinery development and purchase is warranted only under rare circumstances. If timely innovation is impeded by distortions in the incentive structure, a gradual dismantling of distortions may be a more effective long-run strategy than public support for agricultural machinery. This finding will, however, clearly depend on the impact of the machinery on costs and benefits.

A second benefit from the IRRI small machinery program has been its impact on the level of R&D of manufacturers participating in the industrial extension program. These companies are given design information, training, and technical support in the initial stages of fabricating IRRI-designed equipment. A question frequently asked is whether dependency on outside assistance lowers levels of innovation and inventiveness of participants compared with firms not participating in the program.

In a carefully researched study, Mikkelsen (29) gathered information from a sample of 56 metal-fabricating firms located throughout the Philippines. Twenty-seven of the firms were participants in the IRRI Industrial Extension Program. Using as a measure of innovativeness the number of patents obtained and the number of modifications made, Mikkelsen demonstrated that, far from becoming dependent on IRRI, these firms exercised considerable initiative and ingenuity to enhance their products. Because IRRI does not provide exclusive manufacturing rights to a single firm, each cooperator in the IRRI program attempted to improve and differentiate his machine from others following the IRRI design. During 1975-83, 18 firms involved in the IRRI program filed patent applications, more than 50% of which were utility patents consisting of modifications to the original IRRI design. Only two were for inventions. Contrasted with the nonparticipants in the sample, this represented a significantly higher level of innovativeness. In addition, the longer the firms were associated with the IRRI program, the greater the number of modifications introduced and the more research and development activities internalized. According to Mikkelsen, IRRI research "has augmented private invention without reducing it, and possibly even increased the level of invention in its cooperating firms."

CONCLUSIONS

The development and extension of the axial-flow thresher have clearly been a success in the Philippines and Thailand. Equally clear has been the need for a long, sustained, and well-funded effort to ensure this success.

What lessons can be learned from this case study of engineering innovation?

General findings

1. Proper engineering design and development activities require a sustained commitment of resources with a well-focused and identified need.

2. An integrated approach involving market assessment, product planning, design, testing, and extension is essential if viable products are to be developed and successfully marketed.

3. Rural hardware development requires a clear perception of farm-level production and postharvest systems.

4. Public-supported engineering R & D for agricultural equipment should be transitory and undertaken only through a strong link with private sector firms and with the goal of institutionalizing these activities in commercial firms.

5. The most viable environments for engineering R & D will be countries in which sustained agricultural development is under way; where there are disincentives to initiatives by individual firms; where the farm equipment industry is fragmented; and where the social opportunity costs of resources are in reasonable balance with private prices.

Specific findings for the axial-flow thresher

1. The purchase and use of the thresher have been most successful in Thailand, followed to a lesser degree by its acceptance in the Philippines. Larger farm size, an expanding land frontier, and the relatively higher opportunity costs of labor have made the machine an attractive investment and a viable alternative to traditional threshing in Thailand.

2. The major incentive for adoption of the thresher is its impact on costs. Evidence from the Philippines indicates some increased yield through lower grain loss. In the Philippines, the major source of savings has been the reduction in harvesting-threshing shares formerly paid to labor. Landless labor has been reduced slightly, although the participation rates for women and children have increased following the introduction of the thresher.

3. The private profitability of the thresher is very high in both countries, particularly in the early years following release of the design. Over time, the contract rates for mechanical threshing have stabilized at an equilibrium level approximating the cost of traditional alternatives available in each country.

4. Adoption of the axial-flow design by private manufacturers was rapid in both countries, a result of the intensive IRRI extension effort to demonstrate and promote the design and to provide technical assistance and training to cooperating firms.

5. Individual manufacturers have been quick to innovate and modify the design, principally to differentiate it from similar machines produced by other firms. This process has stimulated a higher level of innovation among cooperating firms compared with noncooperators.

6. There is little evidence of direct government intervention in the farm machinery industry in either Thailand or the Philippines. However, the indirect effect of policies influencing foreign exchange rates, interest rates, tariffs on fuels and imported components, and the availability of credit has had little impact on the social profitability of the threshers, although there is evidence of a significant difference between the private and social costs of the machines. Policy instruments have tended to subsidize threshers in the Philippines to a considerably greater extent than in Thailand, although the net social benefit remains positive.

7. The rate of return on funding resources used to develop, extend, and support the axial-flow thresher was high and considerably above that required to justify most public sector investments.

Summary

It would be conjectural to say whether the axial-flow or a similar design would have emerged in the absence of formal R & D work conducted at IRRI. It is highly unlikely that a design as efficient or as widely adopted would have resulted from private sector initiatives within the same period. The evident lack of incentives and support for private investment in R & D on small farm machinery would undoubtedly have delayed development of such a machine for many years.

The axial-flow thresher is a clear case of a viable product resulting from a well-focused, integrated engineering design and development program with a high degree of accountability. Unfortunately, the result is the exception rather than the rule among publicly supported industrial development institutions operating in the Third World.

The conclusions of this paper do not suggest that support of public engineering programs is warranted. In the case of IRRI, funds allocated to engineering also had a very high opportunity value in other research endeavors such as genetic improvement, disease and insect control, water management, and training. Furthermore, the IRRI engineering program has produced other designs that have not had the same degree of commercial success enjoyed by the axial-flow thresher. If the cost of these projects were aggregated into an overall return to the IRRI machinery program, benefit-cost levels would have been substantially lower than those attributed to the axial-flow thresher examined in isolation.

ACKNOWLEDGMENTS

The author gratefully acknowledges the research support and data provided by Ms. Fleurdeliz Juarez of the IRRI Agricultural Economics Department, whose research on rice threshing technology comprises an important share of the contemporary literature on the topic. Ms. Leonarda

Ebron and Ms. Renu Pathnopas contributed substantially to the data base used in the report and to the impact study on mechanical threshers and employment in the Philippines and Thailand. The present analysis also draws liberally from an earlier report prepared by Smith and Duff (39) that examines the efficiency of mechanical threshing and its impact on both productivity and equity in the Philippine setting. Ms. Smith's contribution to the present report is a substantive one. An earlier version of this publication appeared as Chapter 3 of *Macropolicies for appropriate technology* published by Westview Press.

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