Chapter 54 Agricultural Mechanization: Adoption Patterns and Economic Impact

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Chapter 54

AGRICULTURAL MECHANIZATION: ADOPTION PATTERNS AND ECONOMIC IMPACT*

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Contents

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Abstract

Over the past half a century developing regions, with the exception of Sub-Saharan Africa, have seen labor-saving technologies adopted at unprecedented levels. Intensification of production systems created power bottlenecks around the land preparation, harvesting and threshing operations. Alleviating the power bottlenecks with the adoption of mechanical technologies helped enhance agricultural productivity and lowered the unit cost of crop production even in the densely populated countries of Asia. Economic growth and the commercialization of agricultural systems is leading to further mechanization of agricultural systems in Asia and Latin America. Sub-Saharan Africa continues to have very low levels of mechanization and available data indicate declining rather than increasing levels of adoption, even among the countries that were the early trendsetters, such as Kenya and Zimbabwe. This chapter documents the trends and sequential patterns in the adoption of mechanical technology, assesses the evidence on the productivity and equity impact of mechanization, and discusses the implication for mechanization policy.

Keywords

agricultural mechanization, adoption, labor productivity, impact

JEL classification: O13, O14, O31, O32, O38

1. Introduction

Over the past half a century developing regions, with the exception of Sub-Saharan Africa, have seen labor-saving technologies adopted at unprecedented levels. Intensification of production systems created power bottlenecks around the land preparation, harvesting and threshing operations. Alleviating the power bottlenecks with the adoption of mechanical technologies helped enhance agricultural productivity and lowered the unit cost of crop production even in the densely populated countries of Asia. Mechanization of agricultural operations was very selective and sequential; power-intensive operations such as land preparation, threshing and milling were readily mechanized. While operations that require more human judgment, such as weeding, continued to be done by hand under low wage conditions.

Economic growth and the commercialization of agricultural systems is leading to further mechanization of agricultural systems in Asia and Latin America. The advanced countries of East Asia have a completely mechanized rice production system, while the rapidly growing countries of Southeast Asia are moving in that direction [Pingali (1998)]. Middle income countries of Latin America, such as Brazil, Chile and Mexico, are observing a similar rapid shift to labor-saving technologies, both mechanical as well as chemical. Conservation tillage in association with herbicide use has resulted in significant cost savings in cereal production systems in Brazil and Argentina [Ekboir (2000)]. Also in Latin America, vertical integration of the post-harvest processing industry is leading to the replacement of small village-based post-harvest facilities with large-scale processing plants [Balsevich et al. (2003)].

Sub-Saharan Africa continues to have very low levels of mechanization and available data indicate declining rather than increasing levels of adoption, even among the countries that were the early trendsetters, such as Kenya and Zimbabwe. The persistent low levels of mechanization in relatively land abundant Sub-Saharan Africa has been a longstanding puzzle in the literature on agricultural mechanization [Pingali, Bigot and Binswanger (1987)]. The explanation is in the driving forces of agricultural intensification and the incentives for increasing productivity growth. Agricultural areas facing relatively inelastic demand conditions, due to low population densities and/or poor market infrastructure, tend to persist in low intensity, low yield subsistence production systems. The move to mechanical technologies for land preparation is not cost-effective in such societies. Attempts to expand the area under cultivation and to modernize agriculture by bringing tractors into such areas have consistently failed. Tractors by themselves are not an effective tool for inducing the process of agricultural intensification and productivity growth.

The critics of mechanization have argued that the widespread use of labor-saving technologies has had serious equity consequences in terms of the displacement of labor and tenant farmers. Existing evidence indicates, however, that the equity consequences have not been as severe or as widespread as they are presumed to be. The mechanization of power-intensive operations have had minimal equity effects even in the labor surplus economies of Asia. The switch from manual labor to mechanical or chemical technologies for control-intensive operations, such as weeding, has had adverse equity effects in low-wage countries. However, where markets have been allowed to function with minimal government intervention, control-intensive operations continue to be performed by human labor until wages rise due to increased labor withdrawal from the agricultural sector. Serious equity consequences are invariably associated with policies that inappropriately promote mechanization, such as subsidized credit for tractor purchase.

This chapter documents the trends and sequential patterns in the adoption of mechanical technology (Section 2), assesses the evidence on the productivity and equity impact of mechanization (Section 3), and discusses the implication for mechanization policy (Section 4).

2. Trends and patterns in agricultural mechanization

Agricultural operations can be grouped according to the relative intensity with which they require power, or energy, in relation to the control functions of the human mind, or judgment. Operations such as land preparation, transport, pumping, milling, grinding, and threshing are power intensive, while weeding, sifting, winnowing, and fruit harvesting, for example, are control-intensive operations. The shift of the source of power from human to animal to mechanical power is dependent on the level of power intensity and control intensity of the operation [Binswanger (1984)]. Table 1 offers a comparison of operations according to their power intensity and control intensity and the sequence of their transfer to the new power source.

In both land scarce and land-abundant economies the power intensive operations are the ones to be mechanized first, while the mechanization of control intensive operations occurs much later and is closely associated with the wage rate. The sequence, in which power intensive operations are mechanized, however, differs according to land

Table 1
Comparison of agricultural operations according to their power and control intensity

Nature of operation and source of power	Low control intensity, high power intensity	Intermediate intensity	High control intensity, low power intensity
Stationary operations	Grinding, milling, crushing Water lifting Threshing, wood cutting		Sifting, winnowing
Mobile operations	Transport Primary tillage	Harvesting root crops Harvesting grain crops Secondary tillage and interculture	Weeding and harvesting tea, coffee, and apples Seeding

Source: Pingali and Binswanger (1987).

endowments. In land-scarce economies the pumping operation is generally the first to be mechanized, using diesel and electric pumps. Pumps provide a supply of water for double or triple cropping and allow the expansion of cultivation onto marginal lands. Mechanical mills, tillage, and transport equipment follow the adoption of pumps. In land-abundant economies, the use of pumps is delayed until conditions of land scarcity emerge; milling and transport operations are the first to be mechanized, followed by tillage where its mechanization is feasible. The threshing operation, although power intensive, is generally not mechanized where wages are low and harvested volumes are small. Even when land is abundant, therefore, if agricultural production is mainly for subsistence, threshing is the last of the power intensive operations to be mechanized.

The mechanization of power-intensive operations has taken place rapidly even in countries with high population densities and low wages, such as India, Bangladesh, and the Philippines [Herdt (1983); Pingali and Binswanger (1987)]. Mechanization reduced the costs of power-intensive operations significantly as well as ensured their timely completion. Mechanization of control intensive operations is more closely associated with the wage rate. In land-scarce economies in which nonagricultural demand for labor is low, operations such as weeding, interculture, and harvesting continue to be done by human and animal power. Cultivators became prevalent in Japan during the late 1950s, when agricultural wages rose in response to rapid post-war industrialization. It was only in the 1970s that rice transplanters and harvest combines began to be used in Japan [Ohkawa, Shinohara and Umemura (1965)]. In India, and the Philippines, where tractors do tillage and transport, interculture continues to be done by hand and animal-drawn equipment, while harvesting is done only by hand. In land-abundant economies where market opportunities are good and the wage rates are high, many of the control-intensive operations are transferred to mechanical power. This selective nature of the adoption of a new source of power – was also observed in Europe and the United States [Hurt (1982)]. Numerous examples of the sequential adoption of mechanical technologies, for both the developed as well as the developing world can be found in Binswanger (1984), Pingali, Bigot and Binswanger (1987), and Pingali (1998).

2.1. Power tillers/tractors

The levels of adoption of mechanical equipment for land preparation vary significantly by continent, by crop and by farming system. Figure 1 provides a comparison across the three continents of the trends in tractor adoption since 1960 using data from FAO. Intensively cultivated lands of Asia and Latin America have experienced significant levels of mechanization, while adoption rates in Africa, especially Sub-Saharan Africa are extremely low. In fact, one observes a reversal in tractor adoption among some African countries that were thought to be early adopters. In 2002 average tractor use in Sub-Saharan Africa was around 1.3 per 1000 hectares of cultivated land, while in South Asia it was around 9.1 and in Latin America it was around 10.4 tractors for the same time period. Tractor use in Sub-Saharan Africa peaked at 1.9 per 1000 hectares in 1986 and has gradually declined since then. Permanent cultivation systems under grain crops,

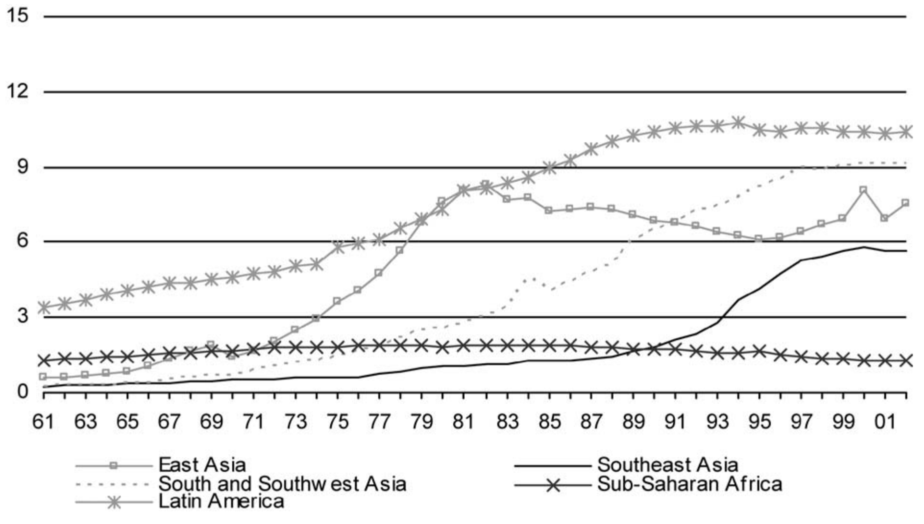

Figure 1. Number tractors per 1000 hectare of crop land – by region. *Source*: FAO (2005).

such as rice, wheat and maize, tend to have higher levels of mechanization relative to less intensively cultivated systems under root and tuber crops.

2.1.1. Asia

In the case of Asia one needs to make a distinction between power tiller and tractor use. Intensive wetland rice production systems in East and Southeast Asia have witnessed a switch from animal drawn plows to power tillers. While four wheel tractors are commonly used for non-rice crops and for dryland environments. South Asia on the other hand has relied much more extensively on four wheel tractors, although power tiller numbers are rising in Bangladesh [Salokhe and Ramalingam (1998); Hossain, Bose and Mustafi (2002)].

Japan and Korea led the rest of Asia in the speed and extent of mechanization and set a pattern that other countries followed. In Japan by 1960, the mechanization of pumping and threshing had already been completed, and the use of power tillers had just started to take off. The number of power tillers on Japanese farms grew from 750,000 units in 1960 to 2.5 million units in 1965 [Kisu (1983)]. By 1965 there was one power tiller for every 2 ha of crop land in Japan [Herdt (1983)]; by 1989, Japan had more than one power tiller per hectare of riceland [Mizuno (1991)]. The Korean experience was similar: number of power tillers rose from a little more than 1000 in 1965 to around 290,000 by 1980 [Cho (1983)]. By 1970, Korea had approximately one power tiller for every 10 ha of riceland [Herdt (1983)], and by 1989, one power tiller for 2 ha of riceland [APO (1991)]. The process of decollectivization in China has led to rapid mechanization of farm operations using power tillers and other small machines. By 1992 China had around 220 power tillers per thousand hectares of riceland [CSO (1993)]. In 1994, 71% of the farm machinery belonged to individuals, 10% to the state, and 19% to collectives [Salokhe and Ramalingam (1998)].

In Southeast Asia, mechanization of ricelands took off in the early 1980s. Power tiller use rose from 26 and 14 per thousand ha of riceland in Thailand and the Philippines, respectively, in 1980 [Herdt (1983)] to approximately 56 and 20 tillers per thousand ha by 1990 [APO (1991)]. Indonesia, Myanmar, and Vietnam have been slower to switch to power tillers for preparing ricelands, reporting less than one power tiller per thousand hectares of rice lands in 1990. Although the situation has changed since then in Vietnam, liberalization of the agriculture sector in the early 1990s has lead to a rapid increase in the adoption of modern rice technologies, including power tillers [Pingali, Hossain and Gerpacio (1997)]. Vietnam today, has the highest number of tractors per 1000 hectares of cultivated land relative to other countries in Southeast Asia. For Thailand and the Philippines, national average figure do not reflect the substantial variation in power tiller adoption by rice environment. The irrigated rice bowl provinces of the two countries tend to be highly mechanized, having more than one power tiller per 10 ha of land, whereas the less favorable rice environments continue to rely on animal power. South Asia is very diverse in terms of the mechanization of land preparation, both across countries and within countries.

Although a superficial look at national average figures would seem to indicate that South Asian countries continue to rely on animal draft power, the intensively cultivated "Green Revolution" provinces, such as the Indian Punjab, tend to be on the same mechanization pathway as similar rice-growing regions in Southeast Asia [Pingali (1998)]. Mechanized land preparation is most advanced in Sri Lanka and least in Nepal. As mentioned earlier, unlike Southeast Asian countries, in South Asia the mechanization of land preparation has emphasized four-wheel tractors rather than power tillers. The larger tractors are more conductive to the rice – non-rice crop rotations that are common in South Asia, more suitable for operating rental markets over a larger geographic area, and more amenable to use as transport vehicles. Tractor numbers in India rose from 0.19 per 1000 hectares in 1961 to 9 per 1000 hectares by 2000, a level that is now at par to that of other developing countries in East and Southeast Asia (Figure 1). Liberalized agricultural equipment import policies in Bangladesh have lead to a dramatic increase in small pump and power tiller use. The 1983–1984 Agricultural Census reported nonexistence of farm machinery except irrigation equipment. The 1996 Agricultural Census, on the other hand, reported ownership of 150,000 power tillers or tractors by 140,000 rural households who constitute 1.2% farm households in the country [Hossain, Bose and Mustafi (2002)]. Mandal (2002) estimates that since then around 15,000 power tillers have been imported annually.

2.1.2. Africa

The first tractors appeared in Sub-Saharan Africa during the period between the wars. They were used initially on settler farms and government-run farms. After 1945, however, tractors began to be used by African farmers also. Most of the postwar imports of tractors were financed by the fund for farm machinery allocated through the Marshall Plan. Since then bilateral and multilateral aid has been supporting the import of tractors for agricultural purposes. Between 1945 and 1981 there were three significant spurts in the number of tractors in use, with intermediate periods of slow growth [Pingali, Bigot and Binswanger (1987)].

The first spurt came around 1945 under colonial influence, and the countries that started to promote the use of tractors during the period 1945–1955 – Zimbabwe, Kenya, Zambia, and Malawi – can be called the first generation of tractor users. The use of tractors in these countries spread from colonial farms to private farms owned by native Africans. The second spurt of tractorization came between 1958 and 1970 and it can be characterized as state sponsored mechanization in some newly independent countries such as – Tanzania, Ethiopia, Ghana, and Cote d'Ivoire. In many of these countries tractors were provided through cooperative farms, state farms, or tractor-hire services.

The third spurt in tractor numbers took place between 1970–1980 when oil and other resource exporting countries, such as Nigeria, Cameroon and the Democratic Republic of Congo tried to re-distribute the gains from resource exports to rural areas. Tractor were purchased and provided to farmers either through subsidized credit schemes or through state sponsored hire-schemes [Pingali, Bigot and Binswanger (1987)].

In a number of countries throughout Sub-Saharan Africa, including Burkina Faso, Niger, Rwanda, Burundi, and Liberia, there was never an organized effort to increase the use of tractors, and the number of tractors is very small. As mentioned earlier, Sub-Saharan Africa has, in fact, fewer tractors per thousand inhabitants than either Asia or Latin America (Figure 1) and the numbers are declining even in countries that experienced the early boost in tractor numbers. The use of tractors was and continues to be restricted to a small commercial farm sector.

Pingali, Bigot and Binswanger (1987) summarize the experiences of tractor projects in Sub-Saharan Africa from 1945 until the early 1980s (Table 2). They identified thirty tractor projects, of which seven were smallholder projects, thirteen were tractor-hire schemes, and ten were block cultivation schemes. Tractor-hire schemes are government-sponsored rental programs for multifarm use of equipment. Block cultivation schemes are group of farms being managed and operated as a single unit, often with mechanization and other modern inputs. The following conclusions can be drawn from Table 2: In many tractor project areas no tractors can be found today. Where any tractors are still being used, their use is inevitably associated with rice cultivation. But even these surviving tractors today are privately owned. The transition from the hand hoe to animal-draft power, where its use is appropriate, continued to be made despite the emphasis on tractors. Of the seventeen attempts to bypass animal traction for tractorization only three succeeded, all of them associated with low-land rice cultivation. None of the block cultivation schemes has ever been successful. For an evaluation of the performance of tractors in Sub-Saharan Africa, see Labrousse (1971), Bonnefond (1967), and Kline et al. (1969).

Given that the rapid spread of mechanical equipment has historically been associated with an abundance of land, why has the spread of mechanization in Sub-Saharan

Table 2
Experiences with tractor projects in Sub-Saharan Africa

Number of projects or areas	Individual farm enterprise	Tractor-hire service	Block cultivation schemes
Initial number of projects	7	13	10
Number of areas in which tractors are still used in the original organization form in the 1980s	None	5	None
Number of areas in which tractors are now used under private operation	None	4	2
Number of areas that had animal traction originally	3	7	2
Number of areas in which animal traction is in use in the 1980s	6	9	3
Number of areas in which continued use of the tractor is associated with rice cultivation	1[a]	9	None

Source: Pingali and Binswanger (1987).
[a]Tractor-hire scheme.

Africa been slower than in countries such as India and China, where labor is abundant and wages are low? Pingali, Bigot and Binswanger (1987) explain the above puzzle in terms of the lack of farm level incentives for the intensification of agricultural systems and hence a low demand for substituting out of existing power sources which in Africa is mainly human. Intensification of agricultural systems is associated with rising demand for agricultural products, triggered by growing populations and/or improved access to domestic or international markets. Farming communities facing an inelastic demand for their products, tend to persist in farming practices that are of low intensity and low productivity. Power requirements in such systems are low and can easily be met by human labor. As farming intensities increase, the number of tasks that need to be performed increases as does the energy requirement for each of the tasks, hence the adoption mechanical technology. Pingali, Bigot and Binswanger (1987) observe a positive correlation between the evolution of farming systems and mechanization based on the extensive field research in Sub-Saharan Africa. The numerous failed experiences across Africa indicate clearly that tractors cannot be used as an instrument for driving the process of intensification. Where the demand side factors are in place, agricultural intensification and the adoption of mechanical power occurs in Africa in a similar pattern to Asia and Latin America.

2.2. *Milling and other post-harvest operations*

Postharvest processing operations are extremely labor-intensive and tedious to perform. Miracle (1967) reported, for instance, that to grind a week's supply of maize meal –

thirty pounds – by hand would take from eight to fourteen hours. The same operation would take half an hour with a hand mill and perhaps not more than ten minutes with a motorized mill. The same is true of dehusking rice, crushing sugarcane, grinding groundnuts, and ginning cotton. In most parts of the world these operations have been transferred to stationary machines powered by water, wind, steam, and – more recently – internal combustion engines or electricity.

Water was first used for milling, pounding, and grinding in the first century B.C. in China, and its use for these purposes was fairly widespread between the second and fourth centuries A.D. Water-powered milling had also been adopted in all corners of Europe by the twelfth century A.D. Wind power was used concurrently for milling and lifting water in Europe. With the advent of steam power, mills were transferred to this source of power in the nineteenth and early twentieth centuries in both Europe and the United States. By the outbreak of the U.S. civil war, steam power had almost completely replaced horses and oxen for powering sugar and rice mills and to turn cotton gins. With steam power, three men and a cotton gin could remove the seeds from 1000 to 4500 pounds of cotton a day, which was about a hundred times the amount they could gin without steam power [Hurt (1982, p. 101)].

In South Asia, animals have long driven Persian wheels, sugarcane crushers, and oil crushers, but the animals used in these operations are gradually being replaced by diesel and electric engines. In India in 1973 the number of stationary engines for power-intensive operations was about twenty times the number of tractors (India 1975 and 1976). In all of Asia mechanical milling of large traded quantities of rice had already been introduced in the late nineteenth century, usually by steam engines, later by internal combustion engines. Smaller rice mills have swept across Asia since the 1950s, and it is hard to find villages where rice is still pounded by hand.

Mechanical mills were introduced in Africa after World War I and spread rapidly through the continent. There is documentation of the earlier existence of water mills in Angola and Kenya [Manners (1962); Jones (1959)]. Jones (1959) and Miracle (1967) have reported widespread use of mechanical mills, both hand and motorized, across Sub-Saharan Africa. Pingali, Bigot and Binswanger (1987) provide evidence from Sub-Saharan Africa indicating that low intensity of farming is not a constraint to the adoption of mechanized mills. This is mainly because the labor input required for milling is independent of the intensity of farming, and mills are rarely owned by the individual households who use them. The service is provided on a charge-per-unit basis by private entrepreneurs or village cooperatives. Since mills do not face any of the timeliness problems associated with plows, efficient rental markets are easily established and the cost of the equipment is spread over many users.

2.3. *Harvesting and threshing operations*

The mechanization of harvesting and threshing tends to follow a two phase pattern. In the first phase, harvesting continues to be done by hand, but threshing is increasing conduct by mechanical means. The second phase is characterized by the adoption of harvester combines that provide for the complete mechanization of both operations. The first phase starts even under low wage conditions, but where peak season labor scarcity emerges around the harvesting period due to growing off-farm employment opportunities. Peak season labor scarcity problems are aggravated in areas where two or more crops are grown on the same field each year. In this case, the labor peak for harvesting blends into the labor peak for land preparation and seeding (transplanting) the next crop. The switch to harvester-combines occurs as economies grow and rising real agricultural wages are observed.

In this connection it is useful to examine technological change in threshing operation in early U.S. agriculture as documented by Hurt (1982). Until 1850 colonial farmers, particularly those in New England, used the hand-held flail to thresh grain from the heads. The flail consisted of a short wooden club attached to a long handle by means of a piece of leather. In the midwestern states, where harvested quantities were much larger, farmers used oxen or horses to tread the grain from the heads.

The first horse-powered threshing machine was patented in the United States in 1791, but it was only between 1820 and 1830 that a number of small, simple, inexpensive, and locally made hand- and horse-powered threshing machines began to appear on the market. Most farmers, however, found threshing with the flail to be cheaper than investing in a threshing machine, because the work could be done during the winter, when there was an abundance of cheap farm labor. It was only with the advent of contract threshing operations that mechanical threshing became profitable. Threshing machines were owned by an entrepreneur, who sent a thresher with an itinerant crew from farm to farm. Although contract threshing imposed an immediate cash expense on the farmer, it did free him/her from the capital investment necessary to purchase a threshing machine and enabled him/her to get the crops to the market before prices fell.

Steam-powered threshing machines preceded steam-powered tractors by more than ten years. In less than a decade steam had almost entirely replaced horses for power. By 1880 the Bureau of the Census estimated that 80% of the grain in the principal wheat-producing states was threshed by steam-powered machines. Steam-powered threshing machines were followed in the 1930s by tractor-powered harvester-combines. The adoption of threshers in Europe followed the same pattern. In 1950 agriculture in Japan was in the early stages of mechanization, with many small pedal threshers and power tillers. This happened in response to rising wages caused by a rapidly growing industrial sector. By 1960 there were one thresher per 2.5 ha and one power tiller per 12 ha in Japan [Herdt (1983)].

The use of mechanical threshers did not emerge in South Asia and parts of Southeast Asia until the late 1960s. this is not surprising, since wages were low, capital costs high, and harvested volumes small. But where the green revolution raised wages and increased harvested volumes, small threshers were rapidly adopted in Indian Punjab, the Philippines, and Central Thailand as soon as efficient designs were available. By the early 1980s the new threshers were penetrating into other South Asian regions [Walker and Kshirsagar (1981)]. As in the United States in the nineteenth century, these threshers are owned by private entrepreneurs who thresh on a contract-hire basis.

Mechanical threshers are still rare in African agriculture. Threshers are not yet profitable in Africa because the harvested quantities per person are small. Therefore there are two conditions under which threshers would be profitable in Africa: improvements in access to markets or seed varieties leading to increases in harvested output and rapidly rising wages, which would increase incentives for adopting labor-saving technology.

Harvester-combines have been in use in East Asia and in Malaysia for several decades now and are emerging in Thailand, but their spread has been limited in the rest of Asia by low harvest wages and small plot sizes. Although harvest wages are relatively low compared with those in developed countries of East Asia, they are rising, and the prospects are that over the next decade mechanization of the harvest operation will be demanded in Southeast Asia.

Small harvesters are seen as an intermediate step in the transition to harvester-combines in much of Southeast Asia. In the absence of land consolidation and the re-design of riceland to form large contiguous fields, the prospects for large-scale adoption of the harvester-combines are limited. Small harvesting machines have been used in Malaysia since the mid-1980s; they began emerging in Thailand in the early 1990s and are expected to be gradually available commercially in other Southeast Asian countries [Pingali (1998)].

2.4. Labor substitution for "control-intensive" operations

As discussed earlier, the adoption of labor saving technologies for control intensive operations, such as planting, weeding, etc., is only profitable as wages rise. In the 19th and the first half of the 20th century mechanical alternatives were the only means available for labor savings for these operations. However, since the later half of the last century chemicals, such as herbicides, changes in crop establishment practices, such as direct seeding, and knowledge intensive crop management practices, such as integrated pest management, have emerged as alternatives to mechanical equipment for control intensive operations. The following is a discussion of the attempts to seek labor savings for control intensive operations in rice systems in Asia.

Rice transplanting and weeding operations are both control intensive as well as require high levels of labor, especially female labor, during a narrow window of time in the crop cycle. Several attempts have been made to mechanize control-intensive operations in rice production systems since the Green Revolution [IRRI (1986)]. Mechanical transplanters, weeders, and fertilizer applicators were some of the technologies released by the rice research systems in Asia. With the exception of mechanical transplanters (machine-driven) in East Asia, most attempts at mechanizing crop establishment and crop care activities have failed. The failures can be attributed to the higher cost of using the mechanical technology relative to the alternatives available, as discussed below.

Since 1970 the use of mechanical rice transplanters spread rapidly across Japan, Korea, and China (Taiwan), as wages rose. The use of transplanters in Japanese rice production took off in 1970, and by 1989 there were 2.2 million transplanters in use nationwide [Mizuno (1991)], approximately one transplanter for every 2 ha of arable land. In Korea by 1989, approximately 66% of the area planted to rice was mechanically transplanted [Chang (1991)]. Taiwan has seen similar rapid growth in transplanter use since the late 1970s [Peng (1983)].

The alternative to mechanical transplanting, as a means of saving labor in crop establishment, is to broadcast pregerminated rice seedlings into the field. Direct seeding is not generally possible in the temperate environments, however, because the cold spring temperatures are not conducive to seedling establishment and growth in the field. Rice seedlings are grown under controlled temperatures conditions and transplanted into the field when they are old enough to resist cold stress; by this time, a few weeks in the season, temperatures are warmer.

Mechanical transplanting has not taken off in the humid tropics of Southeast Asia, even under high-wage conditions, such as Malaysia, because direct seeding is possible. Direct seeding eliminates the transplanting operation because germinated seed is broadcast onto prepared (puddled) paddy soils. Most of the irrigated rice in Malaysia is wet seeded. Wet and dry seeding methods are becoming increasingly popular in other rice-producing countries of southeast Asia. Even though chemical weed control costs are higher for direct-seeded rice, the savings in labor cost have been more than the additional cost of herbicide. Empirical studies in the Philippines and Vietnam indicate that farmers who use wet seeding relied more heavily on herbicides than farmers who transplanted. Similarly, in Peninsular Malaysia, 95% of farmers who direct-seeded their rice applied herbicides, at an average herbicide cost of $30/ha. On the other hand, only 46% of farmers who transplanted used herbicides, with average expenditure on herbicides being $4/ha [Moody (1994); Pingali (1998)]. In low wage South Asian countries manual transplanting of rice, using mainly female labor, persists.

Mechanical weeders were introduced into rice systems in the mid-1970s, but their record of adoption was very poor, primarily because herbicides – a substantially cheaper source of weed control – were available. While high-wage countries have used herbicides for several decades, recent trends indicate increasing use in the so-called low-wage countries of Asia (FAOSTAT). The Philippines, Thailand, Malaysia and India more than doubled their herbicide imports in the 1980s [Pingali (1998)]. In these countries, herbicide has been adopted in association with rice direct seeding, which in turn was adopted in response to rising wages to replace the traditional transplanting system.

Attempts to enhance the efficiency of chemical fertilizer use through mechanical technologies allowing deep placement of fertilizer have also generally not succeeded. The long-term decline in global fertilizer prices has reduced farmers' interest in improving fertilizer use efficiency and investing in equipment to do so. The poor performance of fertilizer placement technology has been observed even in the high-income countries of East Asia. Given the proliferation of nonmechanical options for improved crop management, the future for the adoption of machines for control-intensive operations seems rather bleak.

3. Impacts of agricultural mechanization

The productivity impact of the switch to mechanical technologies for agricultural operations is measured in terms of changes in yields, labor savings, area expansion (in terms of increases in cropping intensities), and quality of enhancement of the marketed output. The equity impact, on the other hand, is measure in terms of labor displacement and income distribution effects, particularly for the landless labor households and for women. The productivity and equity impacts of mechanization vary depending on the power intensity of the operation that is being mechanized, the region's land and labor endowments, and the country's level of economic development. Since the mechanization of power-intensive operations has been well under way throughout Asia, several studies have documented the impact, and evidence from these studies is presented below. Few studies of control-intensive operations and quality enhancement technologies are available because the introduction and adoption of these technologies has been sparse. The power-intensive operations considered here are land preparation, threshing, harvesting (small harvesters), and milling (small mechanical mills). The evidence presented below indicates that, for power-intensive operations, the productivity benefits of mechanization consist mainly of labor savings, and the equity implications are minimal, even in labor-abundant, low-wage economies.

3.1. Land preparation

The movement from using animal-drawn plows to tractors or power tillers is considered efficient if yield per hectare increases and/or if labor hours required for land preparation per hectare are reduced. Yield increases are possible only when mechanization improves tilling quality. However, the available evidence indicates that generally no significant yield difference exists between animal draft and tractor tillage. Herdt (1983) found that yield differences between animal draft and tractor farms were negligible after differences in fertilizer use were considered (Table 3). This is consistent with results from South Asia, where more than 50% of farms using tractors had significantly higher yields, but in almost all cases these higher yields were associated with greater fertilizer use [Binswanger (1978)]. If we find no yield differences between animal draft and tractor farms, we must conclude that the transition to tractor-drawn plows is rarely motivated by improvement in tillage quality. Area expansion and/or labor saving must be the driving forces for such a transition.

Pingali, Bigot and Binswanger (1987) reviewed 24 studies on labor use by operation on farms relying on animal draft power and farms relying on tractors in Asia. They found changes in labor use by operation, in total labor use, and shifts in the levels of labor use between operations. Twenty-two of the 24 studies reviewed reported lower total labor use per hectare of crop production for tractor farms compared to animal draft farms. Twelve studies reported reductions in labor use of 50% or more.

The greatest reduction in labor use was for land preparation, with all studies reporting reduction in labor input exceeding 75%. It is instructive to consider cases in which the

Table 3
Summary of studies comparing rice yields on farms that used animal or hand for land preparation with farms that used machinery

Author	Area	Comparison	Reported yield (t/ha)	Fertilizer (urea) (kg/ha)	Adjusted yield (t/ha)
Pudasaini	Nepal (without pumps)	Bullock vs tractors	1.7 2.1	16 164	1.7 1.4
Pudasaini	Nepal (with pumps)	Bullock vs tractors	2.1 2.3	214 264	2.1 2.1
Sinaga	West Java, Indonesia (1979–80 wet season)	Animal vs tractors	4.9 4.9	323 323	4.9 4.9
Sinaga	West Java, Indonesia (3 seasons, 1978–80)	Manual vs tractors	3.8 3.9	285 308	3.8 3.8
Tan and Wicks	Nueva Ecija, Philippines (1979 wet season)	Water buffalo vs tractors	2.6 4	89 129	2.6 3.8
Anuwat	Central Thailand (irrigated–transplanted)	Bullock vs tractors	2.6 2.8	32 48	2.6 2.6
Anuwat	Central Thailand (rainfed broad-cast)	Bullock vs tractors	0.2 0.2	3 2	0.2 0.2
Alam	Bangladesh	Bullock vs power tiller	1.5	n.a.	1.5
Deomampo and Torres	Central Luzon, Philippines	Before vs after tractor and tillers	2.2 2.6	57 79	2.2 2.1
Antiporta and Deomampo	Philippine provinces	Animals vs tractors tillers	2.6 2.8	86 117	2.6 2.5

Source: Herdt (1983).

labor used for land preparation was reduced by 50% or more and trace the effect on other operations. Consider weeding first. Of the 14 cases with 50% or higher reduction in labor for land preparation, only two reported a reduction in weeding labor greater than 25%. Ten reported reduction in weeding labor smaller than 25%, and two reported increases in weeding labor relative to farms relying on animal traction. The situation for harvesting is quite similar. Of the 14 cases with 50% or higher reduction in labor for land preparation, only one resulted in an equal reduction in harvesting labor, nine reported labor reduction less than 25%, and one found increased labor requirements.

These results indicate that labor savings resulting from the transition to tractors are confined mainly to land preparation, where one observes a substantial reduction in labor peak. However, where aggregate area expansion effects exist (including an increase in cropping patterns), one could expect a rightward shift in the demand curve for weeding and harvesting labor, despite the lower per hectare requirements. Rice cropping intensities have increased significantly from the joint mechanization of land preparation and threshing, especially in humid tropical Southeast Asia [Juarez and Pathnopas (1983)]. With the introduction of modern rice varieties and irrigation infrastructure in Southeast Asia, two to three crops of rice can be grown on the same plot of land per year. Because the first crop is usually harvested during the rainy months, the danger that grain would spoil was very high if threshing was not done soon after harvest. Also, fields had to be cleared of the previous crop before irrigation water could be released. Without the use of power tillers and threshers, high intensity cropping could not have been sustained in much of Southeast Asia.

What are the equity consequences of a shift to tractors/power tillers from animal-drawn plows for land preparation? The answer to this question depends on the answers to four related questions. First, did tractor owners expand the size of their operation by displacing tenant farmers? Second, was there a power bottleneck around land preparation before tractors arrived? Third, has total labor use on tractor owners' farms increased or decreased since tractors arrived? Finally, has there been a net transfer of income from tractor owners to agricultural labor? Each of these questions will be examined in turn.

3.1.1. Aggregate area expansion

Aggregate area expansion occurs only when private farms extend into fallow or reclaimed land or when cropping intensity is increased on a given plot of land. Where private area expansion occurs at the cost of other farmers (mainly through the displacement of tenant farmers), there are no benefits from aggregate area expansion; rather, adverse equity consequences are observed. Any inference on the aggregate expansion in agricultural output as a result of an increase in cultivated land area brought about by tractor use would require additional information on where the additional area comes from.

Lockwood et al. (1983) found in Faisalabad, Pakistan, that 70% of the area expansion on tractor farms came from tenant displacement. The remaining 30% came from increasing area rented in, leading to further displacement of tenants. Eighty-eight of the original 105 tenants lost their land when the landowners bought their first tractor. The average size of tenant farm declined from 4.4 to 3.4 ha. This study confirms the earlier findings in the same area of McInerney and Donaldson (1975). Jabbar, Bhuiyan and Bari (1983) reported that 81% of power tiller owners in Mymensingh, Bangladesh increased their cultivated area by expanding into previously rented-out land.

Where uncultivated or fallow land was not available, the promotion of tractors for land preparation led to high levels of tenant displacement. The exception as noted earlier is the growth in rice cropping intensity owing to mechanization, which did not lead to tenant displacement and resulted in positive employment benefits [David and Otsuka (1994)].

3.1.2. Power bottleneck

Mechanization of the land preparation can lead to significant productivity gains with minimal equity effects in areas with a power bottleneck during land preparation. Such bottleneck could occur because of shortage of either labor or draft animals. Labor shortages are most common in sparsely populated areas and in areas with good nonfarm employment opportunities. Peak season labor shortages have also occurred with an increase in rice cropping intensities, as discussed previously, around the harvest operation for one crop and land preparation for the next. Shortage of draft power may occur in sparsely or densely populated areas (in the latter case, shortages occur because maintenance of draft animal is relatively expensive because of the high cost of fodder). Significant productivity benefits accrue to the alleviation of labor and power bottlenecks, through mechanization. The adoption of tractors (power tillers) in areas with a power bottleneck during land preparation could lead to general improvement in income levels.

3.1.3. Total labor use

It was observed earlier in this section that tractor use reduces labor use per hectare for land preparation, but leads to an increase in area cultivated by tractor farms. Where uncultivated or fallow land is available, or where cropping intensities increase, the use of tractors (or power tillers) for land preparation could lead to an increase in labor employment.

3.1.4. Income transfer

Income distributional effects of mechanized land preparation depend on the nature of final demand and the extent of output growth. Consider first areas with an inelastic demand for the food that is produced. These are typically small, closed economies, where neither exports nor imports of food (in this case, rice) are allowed. In such economies the total demand for food is determined only by domestic demand, and any increase in output will lead to a decline in price.

Where final demand is inelastic, aggregate area expansion caused by mechanized land preparation results in a transfer of income from tractor-owning households to landless-labor households. This happens for two reasons: (i) expansion into previously uncultivated areas (or an increase in cropping intensities) results in increased employment opportunities, and (ii) real price of food output declines as a result of output expansion, and since the landless labor are net purchasers of food, the effect of this price decline is analogous to increasing their income. The direction of income transfer is reversed where the opportunities for aggregate area expansion are limited. Here, tractor farms expand into land previously cultivated by tenants and the result is net labor displacement rather than an increase in aggregate output. Where final demand is elastic (open economies, or economies with large domestic demand), aggregate area expansion does not lead to a decline in prices, but a limited amount of income transfer to labor is observed as a result of expanded employment opportunities. If opportunities for aggregate area expansion are not available, the effects are the same as discussed in the preceding paragraph.

3.2. Mechanization of post-harvest operations

Next to land preparation, harvesting, threshing and milling are the most arduous operations in rice production. Consequently, where mechanical technologies for these operations exist and can be profitably used, they tend to be adopted fairly rapidly. Small mechanical mills, for instance, spread spontaneously across the world without any government program promoting them. What have been the productivity and equity consequences of mechanizing post-harvest operations?

3.2.1. Threshers

The late 1970s and 1980s have seen the rapid spread of mechanical threshers in parts of Southeast Asia and parts of India [Duff (1986); Walker and Kshirsagar (1981)]. In any given area, the private profitability (efficiency) of using a mechanical thresher over hand beating and animal or tractor treading is determined by yield benefits of mechanized threshings, marketable surplus generated on the farm, and by labor wages and availability during the harvesting–threshing period.

Proponents of the thresher technology usually argue that the mechanical thresher presents a significant increase in realized yields due to: (i) a more complete threshing of grain than manual or treading techniques; (ii) a reduction in losses caused by repeated handling of both threshed and unthreshed materials; and (iii) an increase in cropping intensity resulting from a lower turnaround time with mechanical thresher use. On-farm experiments comparing manual and mechanical threshing have shown that mechanical threshers reduce grain loss by 0.7 to 6% of total yield [Toquero and Duff (1985)]. However, there have been no studies of actual farmer thresher use to see if such savings are observed in practice. Cropping intensity effect has been discussed above, and to the extent that threshers contribute to sustaining high cropping intensities, thereby allowing more timely completion of operations they have a positive effect on yields.

The existing evidence indicates that the primary motivation for mechanical thresher use is the labor saving benefits. The adoption of a portable axial-flow thresher in the Philippines resulted in a decline in threshing labor requirements from 7.69 labor days per ton of grain for foot treading to 0.81 labor day per ton. In Thailand, the adoption of a large axial-flow thresher resulted in labor savings of 3.50 labor days per ton of grain relative to the traditional threshing by buffalo treading. Consequently, large gains in labor productivity were observed in both cases [Duff (1986)].

Whether the above labor savings actually lead to efficiency gains or not depends on the real wage of threshing labor, the timely availability of labor and other sources of power for threshing, and the nature of final demand. The following generalization is possible: Mechanical threshing is economically efficient where the farmer faces an elastic demand curve for his output and a power bottleneck exists during the harvesting–threshing period either due to high land–labor ratios or due to opportunities for non-farm rural and urban employment. It is important to remember that a combination of elastic demand and a threshing power bottleneck is required for mechanical threshers to be profitable. Equity considerations in thresher adoption center around the source of the labor that is displaced. Surveys in Nueva Ecija, Philippines, showed that postharvest labor on mechanized farms was 25% lower than on farms in which rice was manually threshed. Disaggregated into family and hired labor, the data reveal that much of the labor savings came at the cost of landless households whose labor services declined by 31% [Duff (1986)]. A similar decline in the use of hired labor was observed in Laguna and Iloilo, Philippines [Juarez and Pathnopas (1983)]. Ahammed and Herdt (1983) used a general equilibrium model to estimate the nationwide employment implications of thresher use (among other production methods) in the Philippines. They found that a 1% increase in rice production would generate employment effect of 16,000 labor years if manual threshing is used. The employment effect would be 22% lower (12,400 labor years) if portable threshers are used. Taking all sectors of the economy into account, substituting mechanized threshing for manual threshing would reduce the employment-generating potential of increased rice production by 7%. This overall adjustment depends on urban employment opportunities, the ability of labor to migrate between regions and between sectors, and industrial policies.

A similar analysis in Thailand found that all the labor savings came from family labor and not for hired labor [Sukharomana (1983)]. This is because Thailand has a very favorable land-to-labor ratio and therefore, a very small landless labor class. Traditionally, the threshing operation is done by family labor with buffalo or tractor treading. The use of large axial-flow threshers on a contract basis has resulted in the release of family labor for other activities.

For both family and hired labor, the thresher had a differential impact on men, women, and children. Mechanical threshers considerably reduced the arduousness of post-production tasks. The lighter nature of the work made it possible for women and children to substitute for men in the threshing operation [Ebron (1984)]. Where off-farm employment opportunities exist, thresher use can result in increased incomes of labor households since male workers may be released for other income generation while women and children provide threshing labor.

3.2.2. Milling

The use of small mechanical mills for dehusking paddy or for pounding grain into flour is perhaps the least controversial of all forms of mechanization. Handpounding of grains, the traditional alternative to mechanical milling, is an extremely labor-intensive task usually performed by women. The efficiency gain in the shift to mechanical mills comes from the resulting labor savings. Because much of the rural milling is done piece-meal for home consumption only and because traditional handpounding is done by female household members, switching to small mechanical mills results in substantial gains in leisure time for women. Consequently, one observes the widespread use of small rural mills on a contractual basis.

With one significant exception, small mechanical mills have increased efficiency of food production without adverse equity effects. The exception is Bangladesh where significant displacement of hired labor has occurred as a consequence of mechanical mills [IBRD (1987)]. Traditional rice milling in Bangladesh is done by a foot-operated mortar and pestle known as a 'dheki', which is usually owned by large landowners and operated on a contractual basis by women from landless and low-income households. The ratio of milling costs with the 'dheki' to those with the mill is about 12:1, not counting the transport costs of bringing the rice to the mill. Thus, the mill owners can charge much lower rates for milling than 'dheki' operators.

The rapid spread of mechanized milling has benefited large landowner households, subsistence-farming households, and urban consumers including the urban poor, whose rice prices have been reduced. Female members of large surplus farms have more leisure time, because they no longer have to supervise hired 'dheki' operators. Female members of subsistence farms who previously operated the 'dheki' for their home consumption are relieved from time-consuming and physically-demanding labor. Nonetheless, women from landless families who work for wages have suffered as a result of the mills because of absent alternative remunerative employment. The policy challenge in Bangladesh has been to find alternative employment opportunities for sustaining the incomes of the women of landless and low-income households, without slowing down the growth in small mechanical mills.

3.2.3. Herbicides

Throughout Asia, the ratio between price of herbicide and wage rate has been declining steadily overtime, making herbicide use economically attractive. In Iloilo province, Philippines, the cost of weed control by herbicide in wet seeded rice is less than one-fifth of the cost of a single hand weeding [Moody (1994)]. Similarly, in West Java, Indonesia, and Mekong Delta, Vietnam, the cost of hand weeding is 3 to 5 times the cost of herbicides. Economic analysis of weed control practices in the Philippines indicate that the marginal benefit cost ratio associated with herbicide usage is as high as 16 [Naylor (1996)].

Although economic and technological factors are likely to lead to increased substitution of labor by herbicides, such a substitution may result in short term adverse social consequences. Due to the need to complete weeding within a short time window, farmers traditionally relied on hired labor for weeding. As small and marginal farmers are the main source of hired labor, their income and employment will be adversely affected unless they can find an alternative use of their time. Increase in cropping intensity made possible by improved technology has in the past been able to absorb most of the displaced labor [David and Otsuka (1994)]. The extent to which substitution of labor by capital in agriculture will occur without imposing welfare costs on certain groups depends mainly on government policies on exchange rate, pricing of inputs and outputs and macro-economic policies. To the extent that herbicides are made cheaper relative to labor due to distortionary price policies, substitution of herbicides for labor is socially undesirable. The social costs are of course lower in societies experiencing a rapid withdrawal of labor from the agricultural sector.

4. Implications for mechanization policy

4.1. Tractors are a poor instrument for stimulating agricultural growth

Over the last century there have been several dozen attempts at introducing tractors into areas that are sparsely populated, particularly in Africa, in an attempt to rapidly expand the area under cultivation and increase production. These attempts have consistently failed because the market infrastructure and economic incentives that induce a production response were not present. The end result was a "boom and bust cycle", a rapid expansion in output that was invariably followed by a collapse in local prices and a subsequent abandonment of the newly opened land and the tractors. Tractors ought to be seen for what they are: a potential tool in the production process and not a driver of economic change.

4.2. Agricultural mechanization policy ought to be seen within the context of an overall agricultural growth strategy

A broad based strategy for agricultural growth provides incentives and infrastructure that enables farmers to enhance productivity growth. Macroeconomic policies that tend to discriminate against or tax the agricultural sector need to given as much attention as agriculture sector specific policies. Policies that enhance rural infrastructure are necessary for sustainable productivity growth and overall rural development. Farmers respond to improvements in incentives and market conditions by changing production practices and investing in new technologies, including mechanical technologies. Broadbased rural infrastructure development also reduces the costs to private entrepreneurs that supply technology and inputs as well as market output.

4.3. The demand for motorizing power intensive operations, such as tillage and threshing, is closely associated with the intensification of farming systems, while the mechanization of control-intensive operations, such as weeding, is driven by rising real wages

The need for increased energy requirements with the intensification of agricultural system has been extensively documented in the literature [Boserup (1965); Pingali and Binswanger (1987)]. The movement from land-extensive cultivation systems, such as shifting cultivation systems, to land-intensive permanent cultivation systems increases both the number of tasks performed and the intensity with which they are performed. For operations that require high levels of power, such as tillage, human labor is gradually replaced by animal and then tractor power. In intensively cultivated systems mechanization of power intensive operations is profitable, even under low wage conditions. In such systems, human labor continues to be used for seeding, weeding, crop care, and harvesting. The co-existence of mechanical and human labor disappears as wages rise due to economic growth and the increasing availability of off-farm employment opportunities. Mechanical seeders, herbicides, and harvester-combines substitute for human labor as economies grow. The sequential adoption of mechanization, first for power intensive and then for control intensive operations, is not a historical artefact, it is a farmer response induced by the changing relative prices of factor inputs.

4.4. Promotion of small stationary machines for power-intensive operations such as milling and pumping can have significant benefits for the poor

Small mills have spontaneously and successfully penetrated even the most remote villages around the developing world. Mechanization has released labor, invariably family labor especially women from the arduous task of de-husking, pounding and milling grain, often on a daily basis. Poor households benefit the most, since the released labor can be reallocated for other income earning activities or for leisure. Governments can play a catalytic role in the further spread of mills, first in promoting research and development on mills that are more energy efficient and improve on quality; second in providing credit and other support for rural entrepreneurs to acquire and operate rural mills.

The adoption of small pumps is less spontaneous yet equally crucial for the livelihood of poor rural households. Pumps help stabilize food supplies in drought prone lands, and where enabling conditions exist, the commercialization of smallholder agriculture. The adoption of pumps resulted in the intensification of cropping in the Indo-Gangetic Plains that extend through Northern India and Bangladesh. Small holders were able to grow a dry season crop of rice or vegetables exclusively for the market, hence stimulating overall growth in the rural economy. Governments can play a similar catalytic role, as with mills, in helping small farmers acquire pumps.

4.5. Clearly established property rights could minimize the risk of displacement of small farmers from their land

In both land scarce as well as land abundant economies, tractor ownership is associated with an expansion in area cultivated. In the absence of clearly established rights to land, tractor-induced farm size expansion could come at a cost to the poor. In land scarce economies, tractor adoption has resulted in the displacement of tenant farmers, while in land abundant economies, traditional access rights to land have been impinged upon as tractor farms expand into uncultivated or fallow lands. Inappropriate promotion of mechanization, through subsidized tractor prices or cheap credit programs, tends to aggravate the negative equity impacts without commiserate productivity benefits. Property rights give small and tenant farmers the bargaining power to prevent encroachment or to seek compensation. Formal land titles empower small farmers further by providing them the collateral necessary for acquiring credit for the purchase of machinery and other agricultural inputs.

4.6. Adoption of labor saving technology does not always imply labor displacement

Mechanization has often been seen as having a negative impact on agricultural employment and therefore detrimental for densely populated "labor surplus" countries. In reality the picture is not as straightforward, whether labor displacement occurs or not depends on: the operation, the labor market, and the policy environment. As discussed in this chapter, mechanization of power intensive operations, water lifting, tillage, milling, etc., have minimal labor displacement effects. The adoption of water pumps tend to increase cropping intensity and hence labor requirements. Mechanized land preparation shifts the demand for labor from land preparation to weeding and harvesting operations. While mechanical mills, release female family labor from the arduous task of hand pounding grain. The mechanization of control intensive operations such as weeding and harvesting could have negative employment effects if promoted under low wage conditions. However, if the adoption of labor saving technologies for these operations occurs in response to rising wages, due to growth in the non-farm sector, then the labor displacement consequences are small. Labor displacement problems are most pronounced when mechanization policy is inappropriate and machines are promoted where they are not required, such as low intensity farming systems, or where wage rates and the opportunity cost of labor are low.

4.7. Public sector run tractor promotion projects, including tractor-hire operations, have neither been successful nor equitable

Public sector record as a promoter of tractor use and as a supplier or tractor services has been poor both conceptually as well as operationally. The pervasive misconception that tractors are a shortcut to agricultural modernization has resulted in the inappropriate promotion of tractors in environments where private farmer decisions would not lead to intensification or tractor use. Public sector tractor projects tend to displace the private sector (or prevent its growth) as a supplier of equipment, spare parts and maintenance services. Being donor driven, public sector projects do not build a self-sustaining system for the long term supply of tractors and associated services. Hence the service collapses at the end of the project. Public sector run tractor hire services are a particular case of operational inefficiency and poor longevity. Where economic conditions are right, the private sector has been an efficient provider of equipment and mechanization services. The public sector can play an important catalytic role in promoting private sector supply as well as private initiatives in equipment research and development. The latter in the particular context of unfavorable production environments and communities facing special needs, such as AIDS affected populations.

4.8. Alleviating supply side constraints to mechanization is important, but only where the demand conditions are right and the enabling environment is in place

Lack of or low level of adoption of mechanization is often attributed to supply side constraints, such as the lack of equipment and spare parts suppliers and skilled mechanics that can provide maintenance services. However, its demand side factors, such as unfavorable relative factor prices and market access conditions that are a more plausible explanation of the poor spread of mechanical technologies, especially in Sub-Saharan Africa. The private sector, where it has been allowed to operate freely and where the enabling conditions are in place, has successfully met the demand for equipment and spare parts, as well as for repair and maintenance. Governments ought to play a facilitating role in reducing the transactions costs involved, for farmers as well as for small entrepreneurs, in the acquisition and maintenance of mechanical technologies.

4.9. Conservation agriculture is not a panacea for farming systems that are not mechanized today

Conservation agriculture, which is generally taken to imply the systematic application of planting without tillage, cover crops, and crop rotation, is seen by some as an opportunity for bypassing the need for mechanical power for land preparation. However, it is completely false to link conservation agriculture with mechanization strategy. In mechanized conservation agriculture access to a tractor and to a no-till drill is required and thus brings with it the same set of issues as for conventional cropping systems. In shifting cultivation systems, the question of adopting conservation agriculture is moot since the practices followed by these farmers, such as the incorporation of fallow vegetation minimal land preparation and the use of a dibble stick for seeding are practices that are consistent with principles of conservation agriculture. However, benefits have been shown in hand-till and draft animal systems. No-till technology for manual and draft animal planting systems have been developed that show a reduction in labor requirements coupled with yields that are less impacted by soil moisture deficits. Which is not to say that conservation agriculture has been proven successful in all agro-climatic zones and associated farming systems. In some cases there is competition for plant residues and potential conflicts between the needs of conservation agriculture and pastoral livestock that are yet to be resolved. Farmers in remote locations who face poor market access conditions are unlikely to find the package of practices that conservation agriculture recommends more remunerative. However, this is a problem for mechanization as a whole, not just for conservation agriculture. For a farmer to increase expenditure on inputs requires a market for increased production, with a return that justifies the increased input expense.

4.10. Global integration of food and input markets can have positive as well as negative consequences for small farm mechanization

Global integration of input markets implies cheaper access to mechanical and other technologies. Technologies developed elsewhere can be more easily transferred and adapted to country specific agro-ecological and farming system conditions. On the other hand, the global integration of food markets exemplified by the global spread of super markets could have more ambiguous effects for the small farmer. Modern food systems impose high standards for quality and safety that the post-harvest equipment and handling practices on small farms may not be able to meet. Scale economies may become increasingly important in meeting the quantity and quality requirements of super markets and hence lead to the displacement of smallholders from the emerging commercial food systems. Whether innovations in post-harvest technologies aimed at smallholders can reverse this situation is an open question.

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