Chapter 4

THE EVOLUTION OF AGRICULTURAL MECHANIZATION IN SRI LANKA

Fredrick Abeyratne and Hiroyuki Takeshima

Abstract: Sri Lanka's unique geography and its distinct experiences with machine use in rice and field crop production offer valuable insights into different patterns of mechanization. Rice in Sri Lanka has a substantial irrigation infrastructure, a strong plant breeding system, and historical examples of success in location-specific breeding strategies (Pain 1986). Furthermore, tractor use in rice cultivation grew very quickly, especially given the relatively small amount of arable land in the country and the lack of direct subsidies, but with certain incentives. Though mechanization initially spread for paddy cultivation, machinery has also become popular in varying degrees in the production of other field crops. This chapter explores the spread of mechanization in Sri Lanka, with a focus on the use of four- and two-wheel tractors, and combine harvesters. It first looks at the process of mechanization from a historical perspective. It then conducts demand- and supply-side analysis to identify the opportunities and challenges facing adoption of machinery in agriculture. It concludes with a brief discussion of the implications of the Sri Lankan experience for African countries starting the process of mechanization.

History of Mechanization Evolution in Sri Lanka

In Sri Lanka, the historical evolution of mechanization can be split into two periods by looking at the trends pre- and post-1970. In the pre-1935 period, which consisted of precolonial and colonial times, dry agricultural zones in the country were relatively neglected and mechanization was limited to the processing of plantation crops in the wet zone. From 1935 to 1970, dry-zone irrigation systems were rehabilitated, and farmers were resettled in those areas. Furthermore, four-wheel tractors (4WTs)—characterized as those with greater than 25 hp—were introduced through government-run pools as well as private ownership and incentive schemes for importation. This led to considerable growth in tractor use, especially on paddy fields.

In the period from 1970 to 1977, imports of tractors and other equipment were restricted. From 1977 to 2000, liberalization led to the lifting of these restrictions, which resulted in the further mechanization of rice production and the gradual rise of mechanization in the production of other field crops (OFCs). From 2000 onward, mechanization spread further among certain OFCs. Additionally, following the end of the country's civil war in 2009, there was an expansion of production and the use of combine harvesters, especially in the eastern part of the country and a gradual spread of combine harvesters for paddy harvesting and threshing.

Up to the 1960s

In Sri Lanka, paddy has predominantly been grown under irrigated conditions, while subsidiary food crops or OFCs have been grown under slash-and-burn (chena) conditions without irrigation. Small homesteads have produced perennial crops such as coconut and fruit trees, and were mostly prevalent in the dry zone of the country.

From the mid-16th century through the mid-20th century, foreign occupation was accompanied by massive transformation in the agricultural sector. Plantation crops such as coffee, tea, rubber, and coconuts were introduced to the southwestern parts of the country known as the wet zone (areas with annual rainfall exceeding 2,500 mm). These plantation crops had long been cultivated using manual labor, and machinery had historically been used only for processing outputs. At the same time, in the dry zone (areas with annual rainfall of 1,200–1,800 mm), paddy-based agriculture was neglected and the ancient irrigation works disturbed, if not destroyed.

Just prior to Sri Lanka's independence in 1948, however, there was a revival of paddy-based agriculture in the dry zone, and previously neglected tank irrigation systems were restored. The government led land development and resettled people from the densely populated wet zone to newly opened lands in the dry zone, which had previously been under forest cover. In these new settlements, initial land allocations consisted of 5-acre plots of irrigated land for paddy cultivation and 3 acres of highland. Later allocations were reduced to 2 acres of land for paddy cultivation and 1 acre of highland (Ellman et al. 1976). Whereas the highlands were home to perennial crops such as jackfruit and coconuts, annual field crop cultivation had been mainly restricted to slash-and-burn methods in state-owned forestlands. Under the new settlement schemes, large amounts of these lands began to be used for paddy cultivation using both manual labor and draft animal power (DAP).

In the mid-1940s, demand was rising for draft power and, though the figures are not available, it is known that draft animals were widely used by the 1960s (Siriweera 1989). To meet the increasing demand for plowing the first 4WTs, initially with 25 hp, were introduced into the country. As dependence on draft animals grew, so too did the eagerness to substitute tractors for their use. In the 1950s and 1960s, large-scale imports began of the 25 to 65 hp class of 4WTs, and the 35 to 45 hp class began to gain more popularity (Pillainayagam 1972). During these two decades, approximately 800 4WTs and a few hundred two-wheel tractors (2WTs) were imported annually (Harriss 1977), which was substantial for a country with less than 1 million ha of arable land. By 1962 the total number of registered 4WTs had reached 2,080 (Farrington and Abeyratne 1982a).

In some periods, the import of tractors was facilitated by foreign aid. Between 1965 and 1969, more than 6,100 4WTs and nearly 3,500 2WTs were imported, primarily through foreign aid arrangements (Raj 1972). Part of the increased tractor importation was also induced by lobbying. In the 1950s, there were several occasions when large-scale farmers in the Eastern province demanded to import tractors in order, then, to sell them to private individuals (Farrington 1984). Incidentally, as will be shown later, it was these same farmers who pioneered today's modern use of sophisticated machinery such as combine harvesters, due to their large landholdings.

Tractor use first spread among larger farms. The 1962 Census of Agriculture showed that the intensity of tractor use was greater in areas with a higher proportion of larger holdings (Raj 1972). However, the same census figure suggests that tractor use had also started to spread among relatively smaller farms, including rice farms of 5 acres or less (Raj 1972). In the 1960s, approximately 15 percent of rice area was likely to have been plowed by tractors (Table 4.1). This share is comparable to levels of adoption in some African countries today, an issue that we will return to in our conclusions.

Since the 1970s

The number of tractors and mechanized areas grew considerably following the late 1960s. By 1976, the number of 4WTs had reached 12,873 (Farrington and Abeyratne 1982a, 1982b). Whereas 4WTs had been introduced earlier, 2WTs, or power tillers (5 hp), had only truly begun to spread across Sri Lanka in the latter part of the 1960s. The first popular model was the Sri Lankan–designed, British-made Landmaster; later, Japanese models such as Kubota gained prominence. By the mid-1970s, around 5,000 2WTs had

TABLE 4.1 Evolution of economic structure, employment structure, and mechanization in Sri Lanka, 1960s–2010s

Variable	1960s	1970s	1980s	1990s	2000s	2010s
Sector share of GDP[a]						
Agriculture	30	29	27	23	13	11
Manufacturing/industry	21	26	27	27	29	30
Service	48	44	45	50	57	61
Employment share (%)*						
Agriculture	53[b]	50[b]	50	42	37	30
Manufacturing/industry	12[b]	13[b]	20	23	28	26
Service	35[b]	37[b]	30	35	35	44
Share (%) of rice area plowed by tractors**	15***	45[c]	43[d]	63[c]	85[c]	98[e] (70—2WTs 28—4WTs)
Share (%) of rice area plowed by animals**	—	37[c]	43[d]	34[c]	8[c]	2
Share (%) of rice area to total arable land and permanent crops	29	37	42	42	44	47
Number of 4WTs (1,000)	2–12[f]	12–13[g]	19[h]	—	15[c]	—
Number of 2WTs (1,000)	0–4[f]	5–10[i]	17[j]	—	100[k]	150[k]
Number of irrigation pumps in dry zone (1,000)[l]	—	3	15	60	107	—
Number of combine harvesters sold annually (1,000)[m]	—	—	—	—	—	1–2
Share of rice area (%) under irrigation	—	—	60[n]	—	—	—

been registered in the country. In 1977, 13,300 4WTs and 6,150 2WTs were registered, and by 1980 the numbers of 4WTs and 2WTs had increased to more than 21,000 and 13,000, respectively (Abeyratne 1984). Based on a rough approximation, the share of rice area plowed by either 2WTs or 4WTs had reached 45 percent by the 1970s–1980s (Table 4.1).[1] This was significant because, by the 1980s, rice area accounted for more than 40 percent of

1 The use of tractors for land preparation of paddy plots still varied between agroecological zones. For example, in the 1980s, the adoption rates of tractors for paddy in the wet zone were around 10 percent, as opposed to 70 percent in the dry zone (Kathirkamathamby 1984).

Variable	1960s	1970s	1980s	1990s	2000s	2010s
Overall trends						
4WTs	Introduced in and imported since late 1940s, continuing to today. Earlier, mostly European makes; presently, mostly Indian, Chinese machines. For both plowing and threshing (wheel treading) of paddy lands. Since the 1980s, have been used to plow other field crops fields as well.					
2WTs	n.a.	Sri Lankan–designed British Landmaster introduced in later 1960s. Thereafter, Japanese, Chinese, Indian makes became very popular. Used for plowing, transportation, threshing, and so on.				
Threshers (rice)/winnowers	n.a.	2WT-driven threshers for paddy introduced in 1970s. Farm Mechanization Research Centre–designed and locally manufactured.				
Threshers (other field crops)	n.a.	n.a.	n.a.	n.a.	In early 2000s, green gram and maize threshing machines introduced.	
Combine harvesters	n.a.	n.a.	n.a.	n.a.	n.a.	Introduced for paddy after the civil war ended.
Water pumps	n.a.	Mainly driven by 2WT engines, introduced in 1970s and used extensively since 2000 for other field crops.				

Source: [a] World Bank (2016). b Figures are for 1963 and 1971, respectively, based on Department of Census and Statistics, reported in Athukorala and Jayasuriya (2004, Table 11). c Figures in later sections of this chapter. d Figures in later sections of this chapter, as well as IRRI (1986, 108). e CSAM and UNESCAP (2015). f Raj (1972). g Raj (1972) and IRRI (1986, 109). h IRRI (1986). i Raj (1972) and figures in later section. j Kathirkamathamby (1984). k Biggs and Justice (2013). l Kikuchi et al. (2001). Figure for the 2000s is the figure from year 2000. m Bandara (2013). n IRRI (1986).

Note: — = data not available; 2WT = two-wheel tractor; 4WT = four-wheel tractor; GDP = gross domestic product; n.a. = not applicable. * Because the figures from World Bank (2016) do not add up to 100 percent, each category was adjusted proportionately so that their sums are 100 percent. ** It is also important to note that paddy-harvested area almost doubled between the 1960s and the 2010s, from 523,296 ha to 1,057,406 ha (FAO 2018a). This makes the growth of the estimated share of mechanized paddy area milder than the area indicated by the growth of the number of tractors. *** The figures are very roughly estimated using a back-of-the-envelope method, as described in the appendix.

farm area in Sri Lanka. This means that as early as the 1970s, Sri Lanka had surpassed the mechanization levels of most African countries today. At the same time, the use of DAP declined, with the share of farm households owning water buffalo falling to 40 percent by the mid-1980s (Kathirkamathamby 1984). The share of paddy area that uses tractors for land preparation has consistently risen since then, to around 60 percent in the 1990s, 85 percent in the 2000s, and close to 100 percent in the 2010s (Table 4.1).

The growth of tractors during the early 1970s occurred in spite of restrictions on foreign exchange allocated for imports, with a levy of 55 percent imposed on foreign exchange entitlements for 4WT imports and a 25 percent

import duty on 2WTs. Though restrictive, these were still concessionary compared with levies on other imports. In the latter part of the 1970s, the economy liberalized, and tractor use grew as a result. As part of the liberalization, levies for foreign exchange entitlements on imports were removed and the full value of imported tractors used for agricultural purposes was made tax deductible (Farrington and Abeyratne 1982a, 1982b). By the early 1980s, the average duty on imported items had been reduced to about 5 percent and the business turnover tax that an importer had to pay was reduced to 1–2 percent (Kathirkamathamby 1984).

Tractors were not only useful for land preparation, and their multipurpose uses were well established by the 1970s; 40 percent of all tractor use time in the early 1970s was for nonagricultural work (Harriss 1977). Similarly, a 1979 survey showed that for every 1,000 hours of tractor use per year, 500 were devoted to nonagricultural activities (Kathirkamathamby 1984).

Though 4WTs were widely used only for land preparation, threshing of paddy by treading it with the wheels, and transport, by the 1990s 2WTs had become popular for many other purposes. These included land preparation; powering of threshers, winnowers, and water pumps; and use of the rotovator to chop straw and spread it into the field. In addition, 2WTs also became a popular method for transport of goods and people. Use of 2WTs increased even more after local manufacturing began and the Farm Mechanization Research Centre (FMRC) designed a portable thresher. Hiring of tractors became common during this period as well, and studies done in the early 1990s show that 65 percent of owners of 4WTs hired out their machines, as did 57 percent of 2WT owners (GTZ 1991).

Initially, tractors were mostly used for irrigated paddy agriculture, whereas cultivation and harvesting of OFCs continued to employ manual labor. In the early 1970s, only 25 percent of all tractors in the dry and intermediate zones were being used on nonrice commercial estates (Harriss 1977). Tractor use for OFCs was low partly because these crops were still largely cultivated under slash-and-burn conditions, in which soil fertility could be restored through fallowing rather than tillage (Farrington 1984).

In the 1980s, as slash-and-burn cultivation became less common and fallow periods shortened, it became clear that mechanical sources of farm power were needed for increasing field crop production (Abeyratne, Gunasena, and Tennakoon 1986). For example, by the early 1990s, 31 percent of chili farmers in Sri Lanka has switched to mechanical land preparation (GTZ 1991). This rise in the mechanization of OFC production was supported by legal changes. The first was a ban on forest clearing, which further reduced slash-and-burn

cultivation. The second was the removal of a restriction on using paddy land for OFC cultivation during the yala season (when water is inadequate for paddy cultivation), which had previously been in place in order to prioritize paddy production. This removal led to increased OFC cultivation on paddy lands, especially during the *yala* season.[2] By the 2000s, 4WTs were used for land preparation and as threshing machines, water pumps, micro-irrigation systems, and sprayers for many different OFCs.

Beginning in the early 1980s, economic transformation accelerated, partly induced by the liberalization of the economy. Growth increased in the manufacturing and service industries and led to large-scale migration of youth into new sectors. Furthermore, more workers joined security forces. These labor flows, combined with decreasing fertility rates and increased labor migration to Middle Eastern and European countries, gradually led to labor scarcities in agriculture. These trends have been associated with further mechanization expansion since the 1980s (Thilakaratne and Somaratne 2011).

Public-sector investments into infrastructure and plant breeding are also likely to have played significant roles in inducing the overall growth in mechanization. The country's density of paved roads was historically one of the highest in South Asia, and as early as 1980 had reached 282 meters per km^2 of land area and 1,177 meters per 1,000 people (World Bank 1994, FAO 2018a), which is likely to be higher than in most countries in Africa south of the Sahara today. This allowed for greater transport and use of machinery. The National Agricultural Research Institute (NARI) made substantial investments into adaptive research, and as a result, all of the widely used rice varieties in Sri Lanka by the 2000s were NARI-developed, as opposed to imported (Hossain et al. 2003, Table 5.3). Improved varieties often raise the returns on more intensive tillage and transportation of harvest, inducing greater use of tractors (for example, Takeshima and Liu 2018).

Following the end of the civil war in 2009, large extents of land were recultivated, especially those in the Eastern province that had not been cultivated for nearly three decades. This revival led to increased demand for mechanization in the region. The use of combine harvesters and other accessories such as threshers in rice cultivation grew. For example, in Ampara district 60 percent of farm households used combine harvesters by 2010 and 40 percent used

2 Seasonal variation in rainfall is determined by the southwest monsoon (occurring in March to August, the agricultural season of *yala*) and the northeast monsoon (occurring in September to February, the agricultural season of *maha*).

combine threshers (Epasinghe 2010).[3] In some instances, these services were provided by Indian workers who migrated looking for work operating large machines, as the required skills often did not exist locally. By 2014, most farm areas underwent mechanized land leveling and land preparation, provided by power tillers and 4WTs (CSAM and UNESCAP 2015).

When one analyzes this timeline, one sees that agricultural mechanization in Sri Lanka has gone through an evolutionary process, rather than a simple upward trend in machinery use over time. The types of machinery (and power) in use have been based on changes in incentive and trade policies, evolving crop technology, and economic transformation. The key takeaway is that although use of tractors and combine harvesters has spread widely across Sri Lanka, there remain a number of constraints to mechanization, including the persistence of smallholders and land fragmentation; quality issues associated with imported machines; insufficient competition among custom hiring service providers in some areas; and limited operating and repair knowledge, especially among the youth population. The following sections will take first a demand perspective and then a supply perspective to discuss these opportunities and challenges within mechanization in more depth.

Demand-Side Analysis

A demand-side analysis shows that although mechanization has spread in a smallholder-dominated environment, farm size and mechanization adoption are positively correlated. Furthermore, the demand for machines varies across cropping systems, and recently, rising incomes and labor costs have fueled demand for mechanization. Overall, despite many constraints to mechanization, demand-side factors have been strong enough to consistently induce further use of machinery, and this is likely to persist going forward. These issues are further discussed below.

Holding Size and Machinery Use

The average holding size in Sri Lanka has declined continuously over the last several decades, falling from 1.61 ha in 1960 to 1.08 ha in 1980 and to 0.47 ha in 2002 (Table 4.2). This rate of decline is one of the fastest in South Asia.

3 It is interesting to note that the rice varieties (apart from MI-273) that were popular in 1970 were susceptible to shattering, so engine-powered mechanized harvesting was not recommended for them; even small combine harvesters were tested and found unsuitable, due to small holding sizes and undulating terrain (Pillainayagam 1982). However, breeding of nonshattering varieties has gradually enabled the use of mechanical harvesting.

TABLE 4.2 Declining farm sizes in Sri Lanka, 1960–2002

Year	1960	1970	1980	2002
Average holding size (ha)	1.61	1.24	1.08	0.47

Source: FAO (2018b).

Therefore, the spread of mechanization (especially the growth in tractor use) observed during the last several decades has occurred alongside a continuous decrease in farm sizes.

Current machinery use in irrigated paddy farming is extensive, though its use in OFC cultivation varies and is relatively less in dryland cropping areas.[4] In Sri Lanka today, the average holding size for irrigated paddy is around 2.6 acres, which is generally arranged in contiguous tracts that allow for easy mechanization. On the other hand, the farm size for OFCs varies from 0.5 to 2 acres, and its organization is more scattered (Sri Lanka, DOA 2015). These characteristics are not much changed from earlier years. In 2002, for example, 60 percent of smallholder agricultural operations in Sri Lanka operated less than 2 acres of land, 31 percent operated less than 1 acre, and only 1.4 percent operated more than 10 acres (Sri Lanka, DCS 2002). In addition to smaller holding size, each holding is divided into small plots (*liyaddas*) based on the slope of the land, limiting the use of large machines and the development of economies of scale. In general, farm size has been one of the major constraints to owning large machines such as 4WTs, and thus farmers have relied on hiring them. In the 1980s, ownership of large machinery was therefore skewed toward owners of large holdings (Farrington and Abeyratne 1982a, 1982b), and this pattern has persisted.

Size of holdings has a relationship with the type of machinery used for land preparation, as shown in Table 4.3 and Figure 4.1. As a result, the recent growth of 2WTs relative to 4WTs (Table 4.1) can be associated with the persistence of smallholder farmers in Sri Lanka. Table 4.3 and Figure 4.1 show that with smaller holding size, the use of 2WTs is more prominent. In fact, most farmers, except those in Ampara (both eastern and western), Mannar, Polonnaruwa, and Trincomalee, use 2WTs for land preparation of smaller holdings, and the availability of single-axle 2WTs can help speed farming

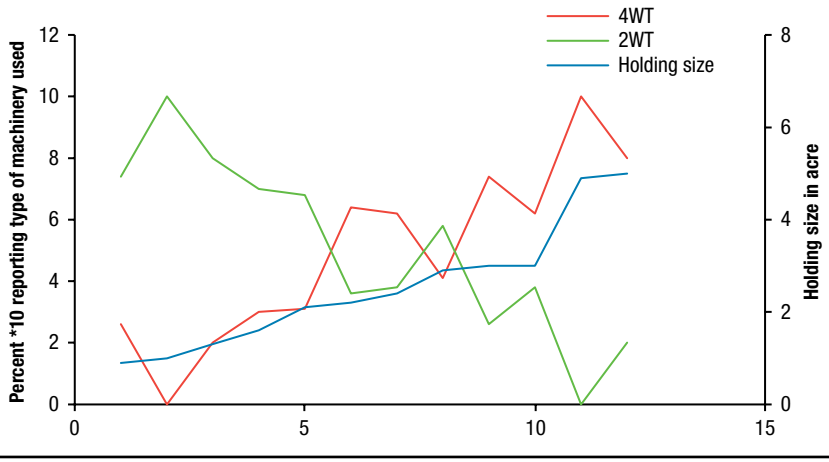
4 Though in the past field crops were exclusively cultivated as rainfed (dryland) crops, increasing numbers of farms are adopting irrigation methods such as drip, sprinkler, and pumped well water.

TABLE 4.3 Holding size and use of machinery for paddy land preparation and harvesting, selected districts, Sri Lanka, 2013/2014

	Percentage reporting * 10			
District	4WTs	2WTs	Combine harvesters	Av. holding size (acres)
Ampara—eastern	10.0	0.0	10.0	4.9
Ampara—western	6.4	3.6	9.0	2.2
Anuradhapura	6.2	3.8	6.6	2.4
Gampaha	2.0	8.0	8.0	1.3
Kalutara	2.6	7.4	4.2	0.9
Kurunegala	0.0	10.0	5.0	1.0
Mahaweli System H	3.2	6.8	6.4	2.1
Mahaweli System B	4.2	5.8	7.8	2.9
Mannar	8.0	2.0	10.0	5.0
Polonnaruwa	7.4	2.6	8.0	3.0
Trincomalee	6.2	3.8	10.0	3.0

Source: Sri Lanka, DOA (2015).
Note: 2WT = two-wheel tractor; 4WT = four-wheel tractor.

FIGURE 4.1 Holding size and use of machinery for paddy land preparation and harvesting



Source: Sri Lanka, DOA (2015).

operations. Furthermore, a significant number of farmers in most districts now use combine harvesters for harvesting and pulling loads.

Farming System and Machinery Use

In the 1970s, about 50 percent of the time use of tractors was dedicated to nonfarm purposes (Kathirkamathamby 1984). Such multipurpose use of tractors continued in later years, and by the 1990s, 2WTs were used by farmers and others in a mix of entrepreneurial operations and services (Biggs, Kelly, and Balasuriya 1993; Kienzle, Ashburner, and Sims 2013). Within the farming sector, machinery use initially developed because of demand from paddy farmers but over time also increased in the field crop sector, largely due to decreasing labor availability and the resulting higher cost of labor. Table 4.4 gives information on labor and machinery costs for the cultivation of selected crops in major production areas across Sri Lanka.

Table 4.4 provides several insights on machinery and labor use over time. For irrigated paddy cultivation, the share of hired labor in total costs rose and fell significantly over the last two decades, going from 32 percent in 1995 to 55 percent in 2005, and finally declining to a period low of 20 percent in 2013. This trend has naturally been coupled with a rising share of machinery costs in paddy cultivation. For OFCs, machinery costs vary based on the type of crop and location. In 2000, machinery was not used for maize production; however, by 2013 it accounted for 31 percent of total costs. This rapid increase in machinery use is likely explained by the introduction of new high-productivity technologies such as hybrid seeds and the increased demand for maize from the livestock feed industry.

Production of the green gram bean, on the other hand, has seen a declining share of machinery costs relative to labor costs. Machinery's share in the total cost of production declined from 36 percent in 2000 to just 15 percent in 2013. Green gram beans must be harvested often, which is a labor-intensive operation. Mechanization of harvesting operations appears to have been slow, so that rising wages resulted in a higher share of costs attributable to labor. Similarly, for red onions (grown mainly in the Jaffna district) the share of machinery in total costs has not changed from 11 percent since 1995, whereas hired labor's share in costs has increased. The case of red onions differs from that of green gram beans, however, because the former's trend was partly due to greater labor availability in the Jaffna district following the decline in war hostilities. Similarly for potatoes, which are mainly grown in the wet zone of Sri Lanka, the use of machinery has been minimal. This is because the wet

TABLE 4.4 Labor and machinery costs for selected crops, Sri Lanka, 1979/1980–2013 (Rs. per acre)

Crop/Expense	1979/1980	1990	1995	2000	2005	2010	2013
Paddy, area (irri)	Apura	Apura	Apura	Apura	Apura	SL	SL
Labor (hired)	384	1,050	2,121	3,462	4,511	7,671	5,293
Labor wage index (Rs. / day)	20	66	135	213	347	697	945
Machine hire cost (buff)	552	1,199	2,132	3,163	4,883	7,955	14,830
TC without FL	1,312	3,413	6,271	10,021	12,870	20,763	26,959
TC with FL	1,694	5,599	10,654	15,217	22,535	35,165	39,917
Maize, area (RF)	Mgala	Mgala	n.a.	Apura	Apura	Apura	Apura
Labor, hired	235	n.a.	n.a.	921	3,728	11,081	9,880
Labor wage index	17	—	—	185	335	693	988
Machine hire cost	0	—	—	0	3,201	5,628	8,861
TC without FL	253	—	—	1,448	11,146	29,443	29,011
TC with FL	597	—	—	8,664	22,087	42,727	45,814
Green gram, area	—	Kgala	Mgala	Mgala	Mgala	Putl	H area
Labor, hired	—	667	726	2,765	3,410	9,002	17,730
Labor wage index	—	50	131	173	310	801	985
Machine hire cost	—	39	0	2,179	3,009	2,626	4,814
TC without FL	—	754	1,599	5,932	7,995	15,968	24,666
TC with FL	—	2,500	6,105	7,583	15,912	30,707	38,738
Chilies, area	Apura (DC)	Apura (DC)	Apura (DC)	Apura (DC)	Apura (GC)	Apura (GC)	Apura (GC)
Labor, hired	294	3,830	1,240	1,051	8,818	21,417	27,132
Labor wage index	16	66	126	191	309	449	969
Machine hire cost	0	0	0	0	0	4,430	7,022

zone has more hills and uneven terrain, and so machinery use has been more difficult than in the dry zone.

Apart from terrain, the price of crops has also triggered changes in the cropping system. For lower-priced crops such as green gram, importing is a cheap option and as a result, the amount under cultivation has reduced. Such reductions have been accompanied by lower use of machinery. However, with higher productivity and prices guaranteed by strong demand from the livestock feed market, maize production has gone up, leading to increased machinery use. Furthermore, the availability of both motor-driven threshers and tractors for land preparation has increased machinery use. Hence, the

Crop/Expense	1979/1980	1990	1995	2000	2005	2010	2013
TC without FL	448	6,802	8,406	4,949	15,636	50,246	50,116
TC with FL	1,729	9,927	20,541	26,247	42,433	101,925	117,926
Red onion, area	n.a.	Jaf	Mgala	Putl	Putl	Putl	Jaf
Labor, hired	—	7,580	8,520	15,108	22,535	32,160	61,133
Labor wage index (Rs./day)	—	55	132	157	279	536	818
Machine hire cost	—	4,767	4,790	9,161	1,1854	16,603	21,628
TC without FL	—	33,343	41,923	75,524	86,342	139,737	203,876
TC with FL	—	37,672	52,654	77,385	93,853	153,956	239,305
Potato, area (irri)	Badul	Badul	Badul	Badul	Badul	Badul	Badul
Labor, hired	540	6,420	9,537	17,507	23,624	21,488	36,000
Labor wage index	20	81	142	195	340	564	720
Machine hire cost (spra)	54	0	0	3,600	3,506	5,273	8,094
TC without FL	11,745	44,236	95,081	87,230	130,154	178,726	212,799
TC with FL	13,256	56,568	112,576	99,412	163,956	248,563	270,661
Potato, area (irri)	NE	NE	NE	NE	NE	NE	NE
Labor, hired	1,961	18,085	13,398	21,442	36,422	47,903	71,261
Labor wage index	18	116	130	203	382	628	996
Machine hire cost (spra)	171	2,177	1,900	3,600	4,083	4,558	14,791
TC without FL	14,580	119,109	109,145	122,991	162,815	282,810	301,495
TC with FL	15,619	121,078	126,529	138,461	197,597	312,975	337,279

Source: Sri Lanka DOA (2015).

Note: — = data not available; Apura = Anuradhapura; Badul = Badulla; buff = buffalo hire cost; DC = dry chilies; FL = family labor; GC = green chilies; H area = Mahaweli System H area; irri = irrigated; Jaf = Jaffna; Kgala = Kurunegala; Mgala = Monaragala; n.a. = not applicable; NE = Nuwara Eliya; Putl = Puttalam; RF = rainfed; SL = Sri Lanka; spra = sprayers; TC = total cost.

evidence shows that changes in both technological and economic factors can affect the intensity of machine use.

The growth in mechanization for some nonrice field crops has also been associated with the development of a system in which just one crop is grown on the same land over time, also known as monocropping. In the past, the cropping systems in rainfed lands (chenas) were mixed, with the different crop requirements and timing making it more difficult to use machinery. However, with the transition to monocropping, machinery became more popular in the cultivation of OFCs. The shift toward monocropping was partially led by government initiatives. As the country's goal of rice self-sufficiency was achieved,

policies have been redirected to encourage production of OFCs under rainfed and micro-irrigation systems, as well as under major irrigation systems during the *yala* season, when water is not adequate for a full crop of rice. For the 2016 *maha* season, the Ministry of Agriculture decided to produce maize, soybeans, and green gram, most of which are still largely imported, to a great extent under monocropping systems. The area used for OFC cultivation, which was 107,792 ha in the year 2009, is projected to increase to 300,000 ha by 2030 (Colombage 2011).

Corroborating the macro information from the Department of Agriculture, a study by Kumara, Weerakkody, and Epasinghe (2016) showed gradual replacement of draft power by mechanized operations over the years. Table 4.5 provides an example of the Monaragala district, showing that over time the level of mechanization in maize production has grown.

On the other hand, only a small percentage of farmers engaging in finger millet cultivation in the Monaragala and Ampara districts use machinery (unlike for maize cultivation in Ampara), despite the fact that a large percentage are willing (Table 4.6). In Monaragala district, millet cultivation is primarily for commercial sale. Those with machines use them for production, and those without them employ their own manual labor. The relatively high willingness to use machinery suggests that there are barriers to their use in the region, likely due to either availability or cost. These facts, along with low market value for millet, means that this commercial production has not led to greater hiring.

Another noteworthy feature in the demand for machinery is the relationship between total household income and type of machine used. A recent study showed that for higher-income households, there is a tendency to use more high-tech machinery, such as combine harvesters, whereas lower-income households use less sophisticated techniques, such as Agrimec threshing machines (Epasinghe 2010). In agricultural households, a higher percentage of total income comes from nonagricultural sources, and in rural households the average income from nonfarm activities is estimated to be more than twice as high as that from farm activities (Bandara 2013). With an increasing number of youths earning more from engaging in nonagricultural pursuits, machinery use for commercial purposes has increased on their family farms. However, households operating near subsistence levels on smallholdings continue to use manual labor and simple machines.

Finally, even though the growth of mechanization has continuously progressed in Sri Lanka, imported machines have at times been unsuitable for certain locations and have led farmers to dis-adopt mechanized operations (Kumara, Weerakkody, and Epasinghe 2016). Extension services intended to

TABLE 4.5 Power sources used for selected operations in maize production in Monaragala district

	Share (%) of farmers using labor or draft power				Share (%) of farmers using machinery			
Operation	2008/2009	2009/2010	2010/2011	2011/2012	2008/2009	2009/2010	2010/2011	2011/2012
General land preparation	48	50	74	40	—	—	—	—
1st and 2nd plow	—	—	—	—	74	80	100	94
2nd plow only	26	20	—	6	—	—	54	—
Preparation of ridges	—	36	36	—	68	64	74	88
Digging holes & seeding	100	100	100	100	—	—	—	—
Weeding & earthing up	100	100	100	100	—	—	—	—
Fertilizer application	98	100	100	100	—	—	—	—
Harvesting & pulling loads	100	100	100	100	—	—	—	—
Threshing & processing								
2WT-driven thresher	—	—	—	—	64	70	46	58
4WT-driven thresher	22	—	—	—	14	30	54	42

Source: Sri Lanka Department of Agriculture (various years), as quoted in Kumara, Weerakkody, and Epasinghe (2016).
Note: — = data not available.

TABLE 4.6 Awareness, affordability, and use of farm implements for land preparation in finger millet production in study locations

	Share (%) of farmers in Ampara district				Share (%) of farmers in Monaragala district			
Farm implement	Aware of	Affordable	Used	Willing to use	Aware of	Affordable	Used	Willing to use
Disc plow	100	—	—	50	100	—	15	60
Tine tiller	100	—	—	54	100	—	18	70
Agrimec paddy machine, altered	18	—	—	—	100	—	18	18

Source: Hector Kobbekaduwa Agrarian Research and Training Institute survey data (2014), as quoted in Kumara, Weerakkody, and Epasinghe (2016).
Note: — = data not available.

make farmers aware of the locally available machinery to mechanize field crop production have at times been inefficient and further restricted machine use.

Labor Market and Machinery Use

Rising labor costs have been one of the underlying forces for mechanization growth in Sri Lanka. With universal primary education and increased completion of higher education, there is an unwillingness to join the labor-intensive

and relatively less profitable farming industry. This has led to a scarcity of labor, and as a result, a higher cost of agricultural labor. For example, the nominal labor wage rate in the year 2000 was just 200 Sri Lankan rupees (Rs) but had risen to Rs 700 to Rs 1,000 by 2013. Though these wages are still lower than those offered for similarly skilled positions in the manufacturing and service sectors, the increases have nonetheless made it more difficult to afford agricultural labor and have motivated farmers to substitute machinery for labor (Table 4.4).

Another factor driving mechanization is the aging population in Sri Lanka. According to the 2002 census, the youth (15- to 29-year-old) population has been decreasing over time; young people made up 26.8 percent of the population in 2001 and just 23 percent in 2012 (Sri Lanka, DCS 2018; UNDP 2014). Along with that, the population older than 60 is increasing; in 2001 it was only 10.2 percent, but by 2051 it is projected to hit 55.8 percent (De Silva 2007). With fertility declining and life expectancy increasing it is predicted that by 2030, Sri Lanka will have one of the highest proportions of people over 60 years old in Asia (Siddhisena and DeGraaf 2009). These trends further decrease labor availability and motivate increased use of machinery.

In conclusion, some of the major demand-side factors influencing current machinery use in Sri Lanka are holding size, type and value of crop, terrain, import policy for crops, stability of demand and prices for crops, availability of new varieties and technologies, total household income, awareness about availability and suitability of machinery, and labor shortages. In general, changes in technology, land conditions, and the labor market seem to have played the biggest role. Technological innovations allowing for higher yields, and crop-specific market conditions, such as the high demand for maize, have induced greater use of machinery. Increases and changes in land use, such as the rise of monocropping, have also led to an increase in mechanization across different crop types. Finally, rising household incomes combined with the many factors reducing availability of agricultural labor have supported the spread of mechanization.

Supply-Side Issues

In this section, we discuss supply-side issues related to mechanization, with a particular focus on ownership, the hiring market, and local manufacturing of agricultural machinery. There is little documentation of subsidies related to agricultural machinery in Sri Lanka before the 1980s (Raj 1972; Kathirkamathamby 1978). This suggests that the spread of tractor use on rice

TABLE 4.7 Annual sales of farm machinery, Sri Lanka, 2011/2012–2013/2014

Year	2-wheel tractors	4-wheel tractors	Combine harvesters	Sprayers	Transplanters
2011/2012	14,445	7,184	2,160	26,093	—
2012/2013	9,664	5,141	1,099	6,240	23
2013/2014	2,783	1,479	—	—	87

Source: Bandara (2013).
Note: — = data not available.

farms leading up to the 1970s, as shown in Table 4.1, occurred without substantial provision of subsidies. However, there were many other supply-side factors that led to increased machine use.

Sources of Machinery

One of the factors that precipitated the growth in tractor use in Sri Lanka was the formation of state-run tractor pools for hire, which began with 150 tractors gifted from the departing British military. By 1952, the main expansion of tractor services came from the cooperative agricultural production and sales societies' importation of 241 tractors.

By the mid-1960s, however, the official policy shifted toward the promotion of private ownership of tractors, largely sourced through imports. During the 1950s and 1960s, Sri Lanka was importing about 800 tractors annually. The dominance of imports was partially due to policy decisions including preferential import duties (1 percent for tractors), preferential allocation of foreign exchange, and low-interest credit.

In recent years, both the incentives and restrictions governing machine imports have largely been removed. However, imports continue to rise. In Table 4.7, we present statistics on recent annual sales of certain machines, showing that some machine types, such as combine harvesters, have been coming into the country in large numbers. The spike in imports in 2011 is because more land, especially in the northern and eastern areas, came under cultivation after cessation of the civil war. This shows that despite issues with quality of imported machines and a growing base of local manufacturers, imports continue to be an important source of farm machinery supply.

Regulation

The majority of imported machinery is not well regulated, and inflows of low-quality machinery are frequent (Bandara 2013). It is expected that improving the quality of imported machinery could contribute to increased

mechanization of OFCs (Kumara, Weerakkody, and Epasinghe 2016). Meanwhile, it is worth recognizing that despite the issues with quality, machine imports have remained significant over the years.

The effects on local manufacturers of low taxes and other incentives that supported importation of machinery are ambiguous. It is possible that these policies acted as disincentives for local manufacturers, but at the same time it is likely that the availability of cheap, imported machines provided materials for local manufacturers to use for reverse engineering and modifications of imported machines.

Research and Development

One of the mechanization-related policies pre-1980 was the establishment of a machinery designs testing unit in the mid-1960s (Kathirkamathamby 1978). In the 1970s, a public research unit called the Engineering Research and Development Division (later renamed as Farm Mechanisation Research Center [FMRC]) was established. Its responsibilities included machinery design and development, machinery testing and evaluation, field trials and experiments, machinery extension evaluation, and machinery production. The main aim of the research has been to develop equipment that is suitable for varying production environments in Sri Lanka. However, this adaptive research intensified only after the 1970s, by which time tractor use had already spread considerably through the use of imported tractors.

Ownership and Hiring Services

Almost all machinery is privately owned by individuals. This high rate of private ownership has persisted despite varying constraints, including poor purchasing power of individuals, seasonality of use, lack of infrastructure facilities, and a shortage of repair and maintenance services (Bandara 2014). It was through custom hiring services (CHS) offered by these private individuals that agricultural mechanization really spread in the country. Although in some rare cases the state-run agrarian service centers owned a limited quantity of machinery for hiring purposes, their share was largely insignificant. Given how much tractor use spread through hiring services, it is useful to investigate incentives behind such services and the potential effects of machinery ownership concentration among so few owners.

THE MACHINERY HIRING MARKET

Now that Sri Lanka has reached near-universal use of tractors for land preparation, investigating the efficiency of the hiring market is becoming

increasingly important. Studies have shown that farmers' awareness of the availability of new land preparation technologies is imperfect, and the spatial concentration of machinery continues to make hiring fees uneven across locations (Bandara 2011; Kumara, Weerakkody, and Epasinghe 2016). Larger machinery, such as combine harvesters and 4WTs, is mostly owned by large farmers and businesses, whose distributions—and consequently the availability of machines—do not always match the demand for CHS in the local area. It is unlikely that reviving CHS run through cooperatives or state-owned enterprises is a good strategy, given their poor performance in the past. However, it is important to further explore how much more efficiency can be brought into CHS through a mix of individual and group ownership, public–private enterprises, and the effective use of modern technologies such as information and communication technologies.

Combine harvester provision services have also been growing. They are, however, not free from constraints. In certain areas, there is excess supply (in some cases, more than 500 concentrated in one area) and thus reduced hiring rates; estimates suggest that prices have fallen from Rs 15,000 per ha to just Rs 7,500. In other instances, rising labor wages of operators, rising costs of fuel and of repair and maintenance, significant reliance on brokers, and climatic problems such as floods and droughts can pose serious constraints to combine harvester use.

In spite of these issues, there are many options for raising the efficiency of Sri Lanka's hiring market for tractors and combine harvesters (Bandara 2014). For example, establishing government support for private machinery hiring centers through public–private partnerships and also through subsidies or soft loans may have significant benefits, as would training machinery operators free of charge at the FMRC. Also, estimating and enforcing fair market hiring rates that allow for reasonable profit margins could help. Machinery owners would also benefit greatly from better access to the latest technologies, which could occur through coordination between the FMRC and the Farm Mechanization Training Centre. Finally, introducing an effective regulatory system that safeguards all relevant stakeholders would go a long way toward improving the CHS market.

Local Manufacturing of Machinery

In Sri Lanka, the machinery available for purchase by farmers has been of three kinds: (1) locally manufactured equipment, (2) imported equipment or fabricated versions of imported equipment, and (3) imported equipment

modified by innovative farmers to suit their own needs. Of these, imported machinery has consistently made up the majority.

Imported machinery has generally been imperfectly suitable for the different land classes, operations, and types of crops grown in Sri Lanka. This may have resulted in reduced productivity and profitability of farms, even though using these machines is still more profitable than using manual labor. In combine harvester operations, the rate of grain loss remains high, at 20–30 percent. It is true that some innovative farmers have modified available machinery to meet their unique needs. However, in order for these modified versions to be commercially produced, the FMRC would need to test and certify them. Due to long delays in these procedures, such innovations have never reached large-scale commercial production levels (Kumara, Weerakkody, and Epasinghe 2016).

Local manufacturing of agricultural machinery has emerged in Sri Lanka over time. There are several manufacturers in Sri Lanka who produce agriculture machinery, sometimes on a commercial scale, based on the designs of the FMRC as well as their own innovations. There are currently seven such manufacturers supplying various types of machines, including a 2WT-operated disc plow, a 2WT-operated seeder, an altered combine harvester for maize threshing, an Agrimec paddy thresher altered for threshing of finger millet, a SeedMaster (seeder-cum-fertilizer drill), a rotovator altered for earthing up, and a modified FMRC maize thresher.

These local manufacturers have emerged in Sri Lanka despite serious constraints. These include the scarcity of skilled labor and the risk averseness of farmers toward machinery usage (Kumara, Weerakkody, and Epasinghe 2016). Further growth of the local manufacturing industry can benefit from joint ventures with foreign manufacturers, continued and improved political stability, and significant increases in local demand. The Sri Lankan government is also currently promoting local capacity through policies such as exemptions from the corporate income tax, customs duty, value-added tax, and ports and airports development levy. The government is also placing emphasis on raising skill levels for manufacturing and testing, and on establishing business and technology development centers that aim to create awareness, adaptive testing, and demonstrations of machinery.

Conclusions

The spread of agricultural mechanization in Sri Lanka occurred despite several constraints, including the quality of imported machines, persistence of

smallholders, low market value of crops, low productivity of crop production, hilly terrain, and insufficient awareness of available mechanical technologies. As some of these constraints have been removed, mechanization has grown even further. However, it remains important for the Sri Lankan government to address the issues of machine quality, lack of skilled workers, spatial concentration, insufficient incentives for small and medium enterprises and for technology development, and the large farm–dominated machine ownership that leads to an uncompetitive CHS market. However, the example of Sri Lanka has shown that even in the face of considerable barriers, agricultural mechanization can spread rapidly.

The experiences in Sri Lanka offer useful insights for African countries. Sri Lanka initially saw substantial growth in 4WT use, which continued until the 1980s, followed by the gradual takeover of 2WTs. Importantly, during the accelerations in tractor use leading up to the 1970s, relatively few direct subsidies were involved. During the early stage of mechanization growth in the second half of the 20th century, Sri Lanka focused on stimulating imports of a substantial quantity of tractors and other machines, while making significant investments in complementary technologies such as improved crop varieties and irrigation infrastructure. These patterns suggest the importance of technology-induced mechanization at an early stage, which African countries may have to follow. In particular, Sri Lanka has invested considerably in local R&D to adapt these technologies to its tropical, low-latitude nature and to its soil types and physiographic conditions, which are different from the rest of Asia but somewhat similar to West Africa, especially in its rice-growing areas (Moormann and van Breemen 1978). Consequently, the early stages of mechanization occurred while agricultural wages remained low and the sector continued to account for a large share of employment. These early investments may have set the stage for further spread of mechanization later on, which become more driven by income growth of farm households and increases in labor costs.

References

Abeyratne, F. 1984. "Changing Patterns of Farm Technology in Sri Lanka." In *Farm Power and Employment in Asia*, edited by F. Farrington, F. Abeyratne, and G. Gill. Bangkok: Agricultural Development Council.

Abeyratne, F., H. P. M. Gunasena, and D. Tennakoon. 1986. *Shifting Farming towards Stability*. Research Study 66. Colombo, Sri Lanka: Agrarian Research and Training Institute.

Athukorala, P. C., and S. Jayasuriya. 2004. *Complementarity of Trade and FDI Liberalization in Industrial Growth: Lessons from Sri Lanka.* Acton, Australia: Australian National University.

Bandara, M. H. M. 2011. "Country Report." Presentation at Sustainable Agricultural Mechanization Roundtable: Moving Forward on the Sustainable Intensification of Agriculture, United Nations Asia Pacific Center for Agricultural Engineering and Machinery, Bangkok, December 8–9.

———. 2013. "Updates on Sustainable Agricultural Mechanization Technology." Paper presented at Ninth Session of Technical Committee, Centre for Sustainable Agricultural Mechanization, Bhopal, India, October 17–18.

———. 2014. "Status of Custom Hiring System of Farm Machinery in Sri Lanka." Presentation at Second Regional Forum on Sustainable Agricultural Mechanization in Asia and the Pacific, Serpong, Indonesia, September 9–11.

Biggs, S., and S. Justice. 2013. "Rural and Agricultural Mechanization in Bangladesh and Nepal: Status, Processes and Outcomes." In *Mechanization for Rural Development: A Review of Patterns and Progress from around the World*, edited by J. Kienzle, J. Ashburner, and B. Sims, 67–98. Integrated Crop Management, vol. 20. Rome: Food and Agriculture Organization of the United Nations.

———. 2015. *Rural and Agricultural Mechanization: A History of the Spread of Small Engines in Selected Asian Countries.* Discussion Paper 01443. Washington, DC: International Food Policy Research Institute.

Biggs, S. D., A. P. Kelly, and G. Balasuriya. 1993. *Rural Entrepreneurs, Two-Wheel Tractors and Markets for Services: A Case from Sri Lanka.* Discussion Paper No. 242. Norfolk, UK: School of Development Studies, University of East Anglia.

Colombage, S. 2011. "Long-Term Outlook for Non-plantation Agriculture in the Macroeconomic Context." In *Agriculture and Rural Development in Sri Lanka*, ed. W. Wimalaratne, ch. 16. Colombo, Sri Lanka: University of Colombo.

CSAM (Centre for Sustainable Agricultural Mechanization) and UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2015. *Agricultural Mechanization and Testing of Agricultural Machinery in the Asia-Pacific Region.* Beijing.

De Silva, W. I. 2007. *A Population Projection of Sri Lanka for the Millennium, 2001, 2101: Trends and Implications.* Colombo, Sri Lanka: Institute of Health Policy.

Ellman, A. O., D. De S. Ratnaweera, K. T. Silva, and G. Wickramasinghe. 1976. *Land Settlement in Sri Lanka.* Research Study 16. Colombo, Sri Lanka: Agrarian Research and Training Institute.

Epasinghe, S. 2010. "The Impact of Use of Machinery for Paddy Harvesting: The Social, Economic and Environment," unpublished manuscript in Sinhala, Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka.

FAO (Food and Agriculture Organization of the United Nations). 2018a. FAOSTAT database. Accessed April 17, 2018. http://faostat.fao.org.

———. 2018b. *World Census of Agriculture*. Rome.

Farrington, J. 1984. "Technology, Growth and Distribution in Sri Lanka's Paddy Sub-Sector," PhD dissertation, University of Reading, UK.

Farrington, J., and F. Abeyratne. 1982a. *Farm Power in Sri Lanka*. Development Study 22. Reading, UK: University of Reading.

———. 1982b. "The Impact of Small Farm Mechanization in Sri Lanka." In *Farm Power and Employment in Asia*, ed. J. Farrington, F. Abeyratne, and G. J. Gill, 113–137. Bangkok: Agricultural Development Council.

GTZ (German Society for Technical Cooperation). 1991. *Mechanization Survey Report*. Eschborn, Germany.

Harriss, B. 1977. "Paddy and Rice Statistics in Sri Lanka." In *Green Revolution?,* edited by B. H. Farmer, 20–29. London: Palgrave Macmillan.

Hossain, M., D. Gollin, V. Camanilla, E. Cabrera, N. Johnson, G. S. Kush, and G. McLaren. 2003. "International Research and Genetic Improvement in Rice: Evidence from Asia and Latin America." In *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*, edited by R. Evenson and D. Gollin, 71–108. Wallingford, UK: Centre for Agriculture and Bioscience International.

IRRI (International Rice Research Institute). 1986. *Small Farm Equipment for Developing Countries*. Los Baños, Philippines.

Kathirkamathamby, S. 1978. "Status of Agricultural Mechanization in Sri Lanka." In *Proceedings of the International Agricultural Machinery Workshop,* 161–170. Los Baños, Philippines: International Rice Research Institute.

———. 1984. "Agricultural Mechanization in Sri Lanka." In *Development of the Agricultural Machinery Industry in Developing Countries*, edited by A. Moens and A. H. J. Siepman. Wageningen, Netherlands: Center for Agricultural Publishing and Documentation.

Kienzle, J., J. E. Ashburner, and B. G. Sims. 2013. *Mechanization for Rural Development: A Review of Patterns and Progress from around the World.* Rome: Food and Agriculture Organization of the United Nations.

Kikuchi, M., P. Weligamage, R. Barker, M. Samad, H. Kono, and H. M. Somarathna. 2001. "Agro-Well and Pump in Irrigation Schemes in the Dry Zone of Sri Lanka: Past Diffusion, Present Status and Future Prospects." In *Use of Groundwater for Agriculture in Sri Lanka: Symposium Proceedings*, edited by S. Pathmarajah, 1–9. Peradeniye, Sri Lanka: Agricultural Engineering Society of Sri Lanka.

Kumara, S. K., R. Weerakkody, and S. Epasinghe. 2016. "Mechanization in the Field Crop Sector: Situation Analysis," unpublished draft, Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka.

Moormann, F. R., and N. van Breemen. 1978. *Rice, Soil, Water, Land.* Los Baños, Philippines: International Rice Research Institute.

Pain, A. 1986. "Agricultural Research in Sri Lanka: An Historical Account." *Modern Asian Studies* 20 (4): 755–778.

Pillainayagam, M. G. 1972. "A Comparative Study of 2 Wheel and 4 Wheel Tractor Operations and Performance in the Dry Zone." Unpublished.

———. 1982. "Research into Farm Power and Equipment in Sri Lanka." In *Farm Power and Employment in Asia*, edited by J. Farrington, F. Abeyratne, and G. J. Gill. Bangkok: Agricultural Development Council.

Raj, K. N. 1972. "Mechanization of Agriculture in India and Sri Lanka (Ceylon)." *International Labor Review* 106: 315–334.

Siddhisena, K. A. P., and D. DeGraaf. 2009. "A Pace of Its Own: The Demography of Ageing Sri Lanka." *Journal of Population Ageing* 2: 77–99.

Siriweera, W. I. 1989. "Role of Draft Buffalo in Rural Sri Lanka." In *Draft Animals in Rural Development: Proceedings of an International Research Symposium,* edited by D. Hoffmann, J. Nari, and R. J. Petheram. Cipanas, Indonesia: Australian Center for International Agricultural Research.

Sri Lanka, DCS (Department of Census and Statistics). 2002. *Population Census.* Battaramulla.

———. Various years. *Labor Force Survey.* Battaramulla.

Sri Lanka, DOA (Department of Agriculture). 2015. *2013/14 Maha, Cost of Cultivation of Agricultural Crops*. Battaramulla.

Takeshima, H., and Y. Liu. 2018. *The Role of Plant-Breeding R&D in Tractor Adoption among Smallholders in Asia: Insights from Nepal Terai*. IFPRI Discussion Paper 01719. Washington, DC: International Food Policy Research Institute.

Thilakaratne, I. G., and H. M. Somaratne. 2011. "Strategies to Overcome the Scarcity of Agriculture Labor: An Empirical Study of Rural Village in the Dry Zone." *Annals of the Sri Lanka Department of Agriculture* 4: 399–406.

World Bank. 1994. *World Development Report 1994: Infrastructure for Development*. Washington, DC.

———. 2016. World Development Indicators database. https://data.worldbank.org/indicator/. Accessed May 21.

UNDP (United Nations Development Programme). 2014. *Sri Lanka National Human Development Report 2014*. New York.

Appendix 4A: Back-of-the-Envelope Calculation of the Share (Percentage) of Rice Area Plowed by Tractors

The share (percentage) of rice area plowed by tractors in the 1960s in Table 4.1 is calculated in the following way.

First, the population of 4WTs in the 2010s is estimated as 20,000. This is based on the figure of 15,000 in 2002 (as is shown in this chapter), and assuming that it increased only slightly, unlike the increase for 2WTs observed during this period. The figures for 2WTs in the 2010s are estimated as 150,000, based on Biggs and Justice (2015). For the 1960s, the average number of 4WTs is estimated as 5,000, based on various estimates (for instance, the figure for 1962 in this chapter comes from Raj 1972). The average number of 2WTs in the 1960s is estimated as 1,000, based on the fact that importation of several hundred 2WTs per year began in the late 1950s (Harriss 1977), and the number of 2WTs was negligible until 1965 and then increased to 3,500 by 1969 (Raj 1972).

Applying the figures of total harvested area of rice (1,057,406 ha) in 2010–2014, shares of area plowed by 4WTs and 2WTs (28 percent and 70 percent of 1,057,406 ha, respectively; see CSAM and UNESCAP 2015), and estimated numbers of 4WTs and 2WTs as above, we calculate the approximate areas plowed corresponding to each unit of 4WTs and 2WTs in Sri Lanka as 14.8 ha and 4.9 ha, respectively, of paddy area. Note that this is not the actual area plowed by each unit, but rather simply proportions between the mechanically plowed rice areas and the numbers of 4WTs and 2WTs, which allow us to extrapolate roughly the areas plowed in the 1960s, given the numbers of 4WTs and 2WTs in the country in the 1960s.

Using the figures obtained above, mechanically plowed rice areas in the 1960s were estimated by simply multiplying the aforementioned 14.9 ha and 4.9 ha to the estimated numbers of 4WTs (5,000) and 2WTs (1,000), respectively, which led to the estimated mechanically plowed rice area of about 80,000 ha. Based on the average harvested rice area in the 1960s of 523,296 ha, the approximate share of mechanically plowed area is estimated as about 15 percent (= 80,000 / 523,296). However, it should be noted that, given the number of assumptions made, this figure should be interpreted with caution.