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A History of the Spread of Small Engines in Selected Asian Countries

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Contents

Tables

Figures

ABSTRACT

The past 50 years witnessed a remarkable spread of smaller-scale rural mechanization in some regions of South Asia, mostly characterized by the spread of single-cylinder diesel engines. These engines have been used for multiple purposes, such as providing power for shallow tubewell pumps, riverboats, two-wheel tractors, road and track transport vehicles, harvesters, threshers, grain mills, timber mills, and processing equipment. Diverse local market institutions for the buying and selling of water, tillage, transport, and many other services have been associated with the spread of smaller-scale rural equipment. Alongside these smaller-scale patterns of rural mechanization there have been significant increases in the intensity of agricultural production and in broader-based rural development. Despite this evidence, international and local policy debates do not reflect the significance of these patterns of rural mechanization for agricultural and rural development. We begin this paper with a discussion of three main generalizations arising from the spread of smaller-scale technology. We then take up policy issues and start by identifying four themes that explain why this smaller-scale mechanization transformation remained below the horizon in policy debates outside the regions where these changes have been taking place. We end the paper by discussing five ways forward in policy analysis.

Keywords: agricultural mechanization, rural mechanization, custom service markets, agricultural intensification, two-wheel tractors, irrigation, pumpsets, shallow tubewells, backward and forward linkages, rural industries, global technology transfer

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1. INTRODUCTION

In the past few years, patterns of rural mechanization have taken on a new significance with concerns about, among other issues, future global food supplies, food wastage and debates around *land grabs*,[1] food security, rural employment, energy generation and use, and water scarcity. These concerns encompass the broader questions of whether, and under what circumstances, rural development should be seen as an important development goal.

When discussions of future global food supplies are presented in the press, they are often accompanied by pictures of large-scale equipment such as powerful four-wheel tractors (4WTs), large combine harvesters (like aircraft in formation), and large-scale irrigation schemes. In land grab situations, if the land acquisitions are for agricultural production, there is generally a large-scale, highly mechanized agricultural production, processing, and marketing process involved. Articles and pictures of rural economies where smaller-scale mechanization plays a central part in increasing agricultural and other rural economic activities are seldom seen.

Despite the media's presentation, during the past 60 years smaller-scale equipment has been spreading throughout much of East and South Asia. Many Green Revolutions have come about not as a result of the spread of larger 4WT and large combine harvesters but as a result of the spread of smaller-scale equipment such as two-wheel tractors (2WT), shallow tubewells, smaller-scale low-lift pumps, small engines on boats, and artisan-made three- and four-wheel rural transport vehicles. Whereas much attention has been given to the role of high-yielding crop varieties in past Green Revolutions, little has been paid to the equally important role of engineering equipment for timely land preparation and sowing, careful water management, harvesting, threshing, and the local processing, transporting, and marketing of agricultural and other rural products, all of which lead to productivity gains and increases in cropping intensification. And while use of machinery in farming does not directly lead to increase in yields it can facilitate the intensification of production through quicker turnaround times, careful and timely use of water, plant protection, harvesting, and so forth, which do increase yields, reduce losses, and often reduce drudgery.

Most past Asian Green Revolutions relied on cheap energy policies for the agricultural sector through subsidized fossil fuels, electricity, and urea. In addition, agricultural machinery was often subsidized with capital grants and low-interest loans. The future for many South Asian countries will depend on a more careful investigation of the short- and long-term outcomes of alternative patterns of rural mechanization. The purpose of this paper is to examine historical patterns of smaller-scale rural mechanization in South Asia to draw lessons for current and future policy.

In the 1970s and 1980s, there were major *choice of technique* policy debates concerning rural mechanization, but by the 1990s the debates had nearly ceased. Since the 1970s many patterns of rural mechanization have taken place in different parts of the world. In the past, the choices of techniques have been limited to commercially available, Western-manufactured, large-scale machinery. Paradoxically, after the decline of the debates, the choice of techniques greatly expanded in the origins and numbers of manufacturers and expanded in scale to commercial small-scale machinery. In this paper, we focus on the spread of these commercial smaller-scale agromachinery and rural equipment such as 2WTs, low-lift pumps, pump sets for shallow tubewells, hullers and mills, and even riverboats, rural-manufactured three-wheel rickshaws, and four-wheel country trucks, mostly powered by single-cylinder diesel and petrol engines[2] (up to 24 horsepower).

[1] These issues are highlighted for South Asia by Vokes and Goletti (2013).

[2] Single-cylinder internal combustion engines in the West are normally petrol (gasoline) powered as these engines are lighter, are smaller in size, and cost less compared to similar horsepower diesel engines. Historically, in much of Asia, countries have put higher taxes on petrol as it was considered that petrol engines were found in more luxury consumer vehicles. Diesel engines were found more in transport and industry vehicles as well as agricultural tractors. Though diesel engines cost 25 percent or more than petrol engines, the cost of diesel fuel is 10–20 percent lower. When operating costs outweigh capital cost farmers and rural service providers prefer diesel engines.

We use the term *rural mechanization* rather than *agricultural mechanization* because it is only rarely that one can separate agricultural mechanization from other rural economic activities. Paradoxically, the term *tractor* conjures in many people's minds a tractor that is used for agricultural uses. However, in many parts of Asia, tractors and especially 2WTs and 4WTs are often used as much for transportation purposes as for agricultural purposes.

Much of our paper will be an illustration rather than a detailed review for a number of reasons. First, our purpose is to open up the policy debate on rural mechanization rather than examine detailed technical issues. Although technical engineering details are important, so too is historical, economic, and social research information, and it is this overarching policy analysis that is our focus. Second, a comprehensive review is beyond the resources we have at our disposal. Finally, country, local, and regional analysis involving local expertise is probably the most critical policy issue at the moment.

We concentrate on engineering equipment because analysis of engineering technologies appears to have been neglected in past agricultural technology policy debates in favor of plant science. There are of course many situations in which the interaction of genetic changes in crop varieties and engineering technology have played complementary roles, for example, shorter-season crops and equipment needed to decrease turnaround times necessary for intensification (Grandstaff et al. 2008). However, attention has often then been given to the importance of the improved seeds rather than to the engineering technologies that have enabled the intensification and economic use of land, water, soils, timeliness of operations, and so forth.

On the whole, we do not look at larger-scale equipment or its interaction with smaller-scale equipment as it is beyond the scope of this paper. We also avoid the more polarized debates of comparisons of simplistic dualities such as large- versus small-scale, bullock versus tractor tillage, general labor-intensive versus general capital-intensive mechanization. Quite often these types of dichotomies do more to obscure and close policy debates rather than open them up.

Although mechanization has been taking place, there have not been national and global studies of these processes and the outcomes of these changes, especially with regard to the spread of smaller-scale equipment.[3]

[3] We are aware that there are many other studies that cover some of the issues we address here and recommend readers go to those sources: for example, Rigg (2003); Barker, Herdt, and Rose (1985); Molle, Shah, and Barker (2003); Shah (2002, 2008); Erenstein (2012); and Kienzle, Ashburner, and Sims (2013). However, in this paper we focus on what we see as a neglected subject: overall issues of smaller-scale rural mechanization. We feel these issues are all the more important today, in the global economy context.

2. HISTORICAL SPREAD OF SMALLER-SCALE RURAL MACHINERY

In this section, we briefly describe the spread of smaller-scale equipment in selected Asian countries. This is more an illustrative coverage because a more comprehensive examination would require considerable resources because the national data on equipment, histories, institutions, and outcomes is either scattered or unavailable.[4] However, we hope our coverage will be adequate to focus attention on the spread of smaller-scale equipment that has taken place, especially with regard to engines of up to 20 horsepower. The common thread among most of the small machinery is the use of single-cylinder and mostly diesel engines that power 2WTs, pump sets for shallow tubewells and low-lift pumps, threshers, and road and water transport.

Table 2.1 gives a general time line of the historical spread of smaller equipment in some South Asian countries going back to the early 1960s.[5] From this one can see the diversity of patterns found among the countries. What the table does not show are the regional diversities within each country. For instance, within Nepal there are zones with higher levels of mechanization and different agricultural machines compared to the country as a whole. The differences within the country are due to factors such as agrarian structure, topography, remoteness, and proximity to trade route and to other countries. Indeed, higher and lower levels of mechanization in the central west correspond to the regional variations within neighboring states, which indicates cross-border diffusion (Justice and Biggs 2013).

Vietnam

Although we said at the start that we would not engage in the large- versus small-scale mechanization debates, David Biggs (2012) described the Vietnamese history of the spread of small engines that power boats and axial flow pumps against a background of the promotion of large-scale equipment. He reported that in the early 1960s, the South Vietnamese government and a US program were promoting larger-scale irrigation schemes, and at the same time small, 3- to 10-horsepower, US-made engines were silently spreading and used to power small boats and locally made axial flow pumps. After the mid-1980s, these small-horsepower engines (now being made in various countries in East Asia) expanded exponentially into the millions in Vietnam. In this case, the original machines were the US Clinton and Kohler petrol engines. The small, light, 5-horsepower Kohler engines became so ubiquitous that any small engine that powers a boat or a pump is called a "*may ko-le*." Significant to the early spread of the small engines was the way local innovators and rural entrepreneurs redesigned the long-tailed motorboat propellers for use with the "shrimp-tailed" axial flow pumps (Sansom 1969).

Similar to the Nepal experience, the 2WTs initially coming from Japan, Korea, and Taiwan were first replaced by the lower-cost Chinese ones. Also, similar to the Thai and Indian experiences, the Vietnamese government established several engine and 2WT factories with the aid of other Eastern companies with concomitant import substitution. Perhaps the most important observation on Vietnam is that like Thailand and now Bangladesh, there has been a long history of a sustained, smaller-scale rural mechanization process. As with Thailand, larger 4WTs and combine harvesters have found a market share in the county. However, the majority of tillage and other agricultural machinery are powered by smaller, single-cylinder diesel engines.

[4] The current projects on sustainable agricultural mechanization strategies under the Food and Agriculture Organization of the United Nations (FAO) and the UN Centre for Sustainable Mechanization are designed to address many of these issues.

[5] For detailed definitions of two-wheel tractors (2WTs) and their histories, origins, and spread, see the Wikipedia website http://en.wikipedia.org/wiki/Two-wheel_tractor on 2WTs, to which one of the authors (Justice) is a contributing writer.

Table 2.1 Historical spread of select smaller equipment in some Asian countries

Country	Technology	1960 1970 1980 1990 2000 2010 2020
Nepal	2WTs	--Japanese---- ----Korean-Chinese in KTM--Pokhara - --Chinese All Nepal-----------
	Small Engines	--Single cylinder Indian Irrigation Diesel Pump---------Chinese Engines--------------
	Threshers	---Wheat threshers--------------------------Rice threshers--------------------------
Vietnam	2WTs	-- Import Japanese and Chinese-------Vietnamese -----------
	Small Engines	-- USA Engines--------Japanese Engines ---------Chinese Engines for pumps and boats---
	Threshers	
Bangladesh	2WTs	--Japanese, Korean ---Rapid Expansion of Chinese -----I----------------------
	Small Engines	--Japanese Diesel Pump----Rapid Expansion of Chinese for pumps, boats, etc---
	Threshers	---Wheat threshers ------------ Rice threshers -------------------
India	2WTs	-----Japanese Indian tie ups---------------------- Chinese -------------------------------
	Small Engines	-------------Indian Listeriod Diesel Pump--------------------------Chinese for pumps, etc----------------
	Threshers	---Wheat threshers ------------------------- Rice threshers ---
Sri Lanka	2WTs	-----Sri Lankan design UK made -------------- Chinese---
	Small Engines	--British-Indian Listorids------------Chinese diesel---
	Threshers	--------Rice threshers --
Thailand	2WTs	-----Thai developed --------------------- ---
	Small Engines	--USA petrol for pumps long-tail boat ---Japanese -Thai Tie ups ---Chinese diesel and petrol---
	Threshers	----IRRI Axial flow rice threshers developed and manufactured --------------------

Source: Correspondence with W. Chancellor (July 2011) and authors' review of documents in the bibliography.

Bangladesh

Bangladesh also has a long history of smaller-scale rural mechanization in which small engines in rural areas have powered boat and road transportation, pump sets, and 2WTs, among other usages. Before independence, the irrigation policy in Bangladesh concentrated on large-scale canal systems and deep tubewells but with at least half the country being irrigated by local small-scale equipment such as swing buckets and *dhones*.[6] Large heavy engines were used for low-lift pumps in the public and private sectors where rural entrepreneurs were selling water. After independence, the irrigation policy changed radically, and the government promoted groundwater development policies, especially shallow tubewells, and the use of small horsepower, low-lift pumps for lifting water from surface sources. After the change of policy, there was much formal and informal experimentation with different sizes and types of shallow tubewell and low-lift pumps and with different institutional models, such as landless laborer groups selling water and private ownership. However, it was not until the 1980s that there was a major expansion of shallow tubewells powered by Chinese diesel engines, which were cheaper and lighter in weight compared to the conventional Japanese and Indian small-horsepower diesel engines.

Some of the early introductions of 2WTs took place in the mid-1970s when a Japanese aid program established a training center for 2WTs near Dhaka. However, use of the Japanese 2WTs did not spread. During visits to China in the 1970s, Bangladeshi entrepreneurs began to add a few small diesel engines to their container shipments, but it was not until the restrictions on the import of Chinese equipment (because they were considered of inferior quality) were lifted in the late 1980s that the rapid spread of Chinese-made engines (for irrigation) and 2WTs took place. Table 2.2 demonstrates how by 2011 smaller-scale equipment spread in Bangladesh to 420,000 2WTs[7] and 1.4 million shallow tubewells.

Table 2.2 Small machinery used for agriculture purposes in Bangladesh

Machine	1977	1984	1989	1996	2006	2008	2009	2010	2011
2WT	200	500	5,000	100,000	300,000	343,000	366,700	400,030	420,027
Deep tubewells	4,461	15,519	22,448	24,506	28,289	31,302	32,174	32,912	-
Shallow tubewells	3,045	67,103	223,588	325,360	1,182,525	1,304,973	1,374,548	1,425,136	-
Low lift pumps	28,361	43,651	57,200	41,816	119,135	138,630	146,792	150,613	-
Threshers (Open drum)	-	500	3,000	10,000	130,000				190,000
Threshers (Closed drum)	-	100	1,000	5,000	45,000				65,000
Maize sheller				100	850				5,000
Combine harvester						±30			100
Winnower						±500			±200
Backpack sprayer						1,250,000			1,250,000
Reaper						±40			±50
2WT Seed Drills					451	481	620	890	1,220

Source: Table from International Development Enterprises (2012).

Note: 2WT = two-wheel tractor. Dashes indicate not available.

[6] A hollowed-out tree on a pivot used to lift water manually.

[7] As Biggs, Justice, and Lewis (2011) discuss, reliable statistics in developing countries on agricultural machinery are very difficult to obtain. During the Bangladesh workshop where this paper was first given the "updated" statistics provided by many people on the total number of 2WTs in Bangladesh was 600,000 to 700,000 units.

Thailand

The spread of smaller engines in Thailand also has a long history. Grandstaff et al. (2008, 336) describe how the use of 2WTs in the rainfed region of the Northeast of Thailand rose rapidly after the beginning of the 1980s. In 1983 there were 40,000 2WTs, and the number rose to 1,250,000 in 2003. Agricultural-holding households owning 2WTs rose from 2 percent to 47 percent in 2003. By 2003, 89 percent of households were using 2WTs, and hiring practices were widespread. In this case, the 2WTs were part of the intensification of a rainfed rural economy. In other parts of Thailand, the pattern of small-scale mechanization was different. There are 1.8 million 2WTs, and nearly 2 million to 3 million small-horsepower pump sets (Thepent 2011; Faures and Mukherji 2009). The history of Thailand's small-scale pump set irrigation was different from that of Bangladesh as the use of surface water from canals, small rivers, and farm ponds has been much greater. But the importance of small pump sets to pump from these canals is just as important. The types of pumps also differed. In the early 1960s, Thailand developed locally produced axial flow pumps, likely an innovation borrowed from the Vietnam shrimp-tailed/propeller pumps. Although axial flow pumps are one and a half to two times more expensive than conventional centrifugal pumps, they have half or less the energy consumption of centrifugal pumps at lifts below 3 meters. However, Facon (2002) notes that in the mid-2000s there has been an explosion of shallow tubewell development in certain parts of the Chao Phraya delta, which perhaps indicates that the availability of surface water may have reached its limits.

The history of the spread of smaller equipment in Thailand has been characterized by the strong support and promotion by the government of private agromachinery industrial development. Since the early 1960s, there have been substantial programs for the promotion of manufacturing of both the earlier small and the more recently larger agricultural machinery. Chinsuwan and Cochran (1985) describe a government-led program for the development and manufacturing of axial flow pumps. William Chancellor (personal communication, August 2011) reported that the "Thai"-type 2WT was initially developed in the late 1950s by M. R. Debriddhi, head of the engineering division of the Thai Rice Department of the Thai Ministry of Agriculture and Cooperatives[8]. Debriddhi spent many years cooperating with several manufacturers to promote the spread of this technology. Referring to the spread of axial flow rice threshers in Thailand in the 1980s and 1990s, Chancellor also related that the International Rice Research Institute, in the 1970s and early 1980s, "through its newly created Industrial Extension Program had extended axial-flow threshers to Thailand" and that the "government of Thailand had responded with a relatively large program for their promotion with many local manufacturers." Later, Thepent (2009) describes a series of these government projects beginning in 1983 with the development of locally made track-type combine harvesters that led to the first commercially manufactured combines in 1989. Thepent attributes the success of the combines to building on the earlier success in the development of the axial flow rice threshers that were incorporated in the combine harvester's designs.

Today, Thailand is a mixed system where Thai-made 2WTs still do most of the land preparation for rice (although in the last few years 4WTs have begun to spread but mostly in the upland maize areas north of Bangkok) but where larger-horsepower Thai-made threshers and combine harvesters greatly aid in the harvest of rice. Thepent relates that Thai farm holdings continue to fragment and get smaller but that if the high support prices for rice from the Thai government do not continue this could slow or even reverse the land fragmentation (Thepent personal communication, February 2014).

[8] Also see Chancellor (1998).

Sri Lanka

Sri Lanka is especially interesting as regards 2WTs because one of the early designs of a South Asian 2WT was by Sri Lankan Ray Wijewardene in 1955. This model ended up being manufactured in the United Kingdom by Landmaster with exports back to Sri Lanka. By 1975, there were 11,000 2WTs in Sri Lanka. The UK 2WTs gave way to Chinese imports in the 1980s. By 2007, there were 125,000 2WTs in Sri Lanka. As with Bangladesh, these 2WTs are generally used for multiple purposes such as transport, tillage, and harvesting. Rural entrepreneurs who own them, but who do not necessarily operate them, hire out services (Biggs et al. 1993). It is estimated that more than 80 percent of all tillage operations are mechanized, and much of this is done by 2WTs. In addition it is estimated that by 2000 there were more than 100,000 smaller-scale engines used for shallow tubewell pumps (Barker and Molle 2004, 2005; Kikuchi et. al. 2003).

India

Since the 1980s the Indian government has made significant investment in smaller-scale equipment through agricultural research and extension policies. The All India Coordinated Research Project on Farm Implements and Machinery and the various departments of agricultural engineering in the many agricultural universities in India have long-term projects for the research, development, and promotion of small-scale agricultural machinery. Other central and state-funded programs provided large and long-term subsidies for 2WTs and small machinery. However, if one looks at access to powered machinery for tillage, harvest, and threshing, India looks very different from its neighbors. In Bangladesh and Sri Lanka more than 80 percent of tillage operations are mechanized—mainly by 2WTs—whereas in India mechanized tillage and crop establishment makes up 45 percent, (Kulkarni 2010; Pandey 2009; GOI 2013).

The slow spread of smaller-scale equipment in India is a paradox. Table 2.3 shows the percentage of the total 2WTs in the Asian region, by country. The unexpected figure is that the whole of India has only about 300,000 2WTs or 1.5 percent of the total, which is less than the 500,000 2WTs or 2.5 percent for Bangladesh. Ten years ago there was an even wider disparity, with 350,000 in Bangladesh and approximately 120,000 in India. From the 1970s, the government supported Japanese-Indian 2WT joint ventures of which only two survive. From the 1980s to 2000, VST Bangalore from Mitsubishi and Kamco Kerala from Kubota had nearly the whole market to themselves, selling relatively higher-quality but also much higher-priced 2WTs. Recent industry reports state that 2WTs sales started picking up in 2005, and by 2010 the industry had a growth rate around 20 percent per year. Recent sales are reported at upwards of 45,000 to 55,000 per year. In contrast, in 2001, sales were less than 20,000 (Kulkarni 2005). In the 1990s, Chinese 2WTs began making inroads, and today, according to market reports for the past five years, they may have gained 35 percent or more of the market share.[9,10]

As indicated by countries such as Bangladesh, Thailand, and Sri Lanka, the recent rapid spread of smaller-scale machinery has increased the productivity of agricultural and other rural resources. The paradox then is, How is it that even with large government support, investments in the research and development (R&D) as well as in the manufacturing of 2WTs, and the sizable potential for small-scale equipment to increase the intensity of use of agricultural and other resources, the spread of smaller-scale equipment has been so low in India?

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[9] Kulkarni, in *Business Standard,* and Sushhil Finance, also in *Business Standard,* gave a 15–25 percent annual growth rate starting from 2005. Until then the market had been stagnant, with few or even decreasing sales. It is not clear what exactly changed to drive this growth.

[10] Reference the World Bank's (2011) *The Ganges Strategic Basin Assessment,* which states that excluding Bangladesh, much of the eastern Gangetic plains shallow aquifers are underutilized.

Table 2.3 Estimates of the two-wheel tractor population in some Asian countries

	Two-wheel tractors in Some Asian countries (estimates for 2012)	
Country	**Number**	**Percentages**
Pakistan	1,000	<1
Bhutan	3,000	<1
Afghanistan	8,000	<1
Nepal	20,000	<1
Sri Lanka	150,000	<1
India	300,000	1.5
Bangladesh	500,000	2.5
Thailand	1,800,000	9.0
China	17,000,000	85.9
Total	19,782,000	100%

Source: Authors' estimates based on IFPRI (2014), J. Kienzle, J. E. Ashburner, and B. G. Sims, eds. (2013), Wang (2013).

A complete answer to this complex question is beyond the scope of this paper. However, we suggest that part of the explanation is that agricultural mechanization in India has been largely dominated by the corporate manufacturing sector. In particular, the indigenous 4WT industry has seen the entry in the past decade of multinationals such as AGCO/New Holland, John Deere, and Deutz Farh. India became the largest manufacturer of 4WTs in the world in the late 1990s, yet it was accompanied by the neglect of the machinery requirements of cultivators and other rural entrepreneurs in rural areas, especially in the poverty areas of the eastern and central regions of India. Consequently, for the sake of this review of the long-term sustained spread of smaller-scale equipment in the intensification of agriculture and the rural economy, surprisingly India has limited knowledge to share, although that may now be changing.[11]

Nepal

The first 2WTs came to Nepal via Japan in the 1970s. Korean and Chinese 2WTs entered in the 1980s, but as sales were limited to Kathmandu and Pokhara Valleys, sales were slowed and stopped in the 1990s (Biggs et al. 2002). In 2000, sales began anew but only for Chinese 2WTs. Today, it is estimated that there are more than 20,000 2WTs in Nepal, with sales of 1,500 to 2,000 per year.

Japanese and Indian small-horsepower diesel pump sets for irrigation started in the 1970s. However, even with subsidies their sales were always disappointing. Their sales dropped after the subsidy was withdrawn in 2000. In 2004, less expensive and lighter-weight Chinese pump sets entered the market, and sales picked up to 5,000 or more per year. Figure 2.1 illustrates how much the choice of technology has opened up for cultivators and rural entrepreneurs since the 1980s and 1990s when there was only the choice between a Fieldmarshall or Kiloskar, nearly identical, very heavy, and very expensive irrigation Lister-type diesel engine pump sets. Figure 2.1 shows three pictures of a single store in Narayanghat, Chitwan, where there is a wide array of choices from Kiloskar to many sizes of Chinese diesel, petrol, and petrol/kerosene engines as well as a similar wide array of Chinese and Indian electric, above-ground, and submersible borehole pumps.

[11] There is considerable evidence that policy practice is now changing in India, for example, the dramatic rise in the imports of Chinese equipment. The National Bank for Agriculture and Rural Development has undertaken research and is now giving special attention to loans for small-scale equipment.

Figure 2.1 Examples of the wide range of engines available on the market in Nepal

Source: Authors (2013).
Note: These three photographs of a single hardware shop in Narayanghat, Nepal illustrate the wide variety of electric submersible and electric, diesel, petrol, and petrol/kerosene above-ground pumps available on the market in Nepal.

A paradox also exists in Nepal. After the introduction of Japanese 2WTs in the 1970s in the Kathmandu and Pokhara Valleys, 2WTs made significant contributions to increased agricultural productivity in those valleys. However, the paradox is that there was little governmental and donor support for this type of smaller-scale mechanization until the late 1990s. At that point, new demonstrations and research on 2WTs were initiated on the Terai and initiatives taken to encourage the import and sale of 2WTs. There is now an estimated population of 20,000 2WTs in Nepal.

Another paradox in Nepal was that discussions of rural mechanization were left out of early five-year development plans, and the national Agricultural Perspective Plan (APP) in 1996 excluded a discussion of agricultural and rural mechanization. Although the irrigation sector received some recognition in the APP, the critical inputs of small-scale groundwater development and local canal water systems were assumed to be addressed through the technical abilities of other ministries and institutional coordination between ministries. However, little research on the effective, careful use of water at the farmer level took place, and little communication took place. In the early 2000s, the minister of agriculture and the Asian Development Bank (ADB) tried to address these issues and modify the APP, but little changed. Hence, it can be seen that the APP itself was one of the reasons why the intensification of agriculture and the development of the rural economy through smaller-scale rural mechanization was not addressed earlier.

In addition, the main banks in Nepal are still *traditional* and slow to create financial products for poorer people who do not have land or other collateral that would allow them to invest in smaller-scale equipment.

A relatively new entrant onto the mechanization scene of Nepal is the spread of smaller-horsepower 2WTs or mini-tiller tractors shown in Figure 2.2[12] These were initially brought in around 2005 by a few private-sector agricultural input traders who saw them on trips to China. The mini-tillers initially spread in peri-urban areas for vegetable production. There has been some government-sector support,[13] and they are now spreading in rural and mountainous areas where the larger 12- to 15-

[12] These are four- to eight-horsepower rotary tillers that usually come with interchangeable rotovator blades and rubber tires.

[13] Support was initially in the form of training and demonstrations from the Department of Agriculture's engineering directorate. Later, various District Agriculture Development Offices and District Development Committees on their own initatives began buying them for farmer groups. This indicates a new vibrancy on the part of some district-level officers for decentralized public-sector agricultural development.

horsepower 2WTs are too large for the small terraces and difficult access conditions. There are ten or more mini-tiller importers, and they sold an estimated 500 units in 2012. The government of Nepal and donor-funded projects are attempting to backstop their spread and attempting to find additional implements and uses similar to the larger-horsepower 2WTs.

Figure 2.2 Petrol-engine-powered mini-tiller puddling soil for rice on the terraced hills behind Bhaktipur

Source: S. K. Sharma (2014).

Until recently the Nepal importers had offered only mini-tillers with rotovators for plowing. However, government and donor projects that have taken interest in these mini-tillers are now working with the importers to develop and offer other mini implements such as seed drills, irrigation pumps, open drum threshers, milling machines, and trailers that would make these mini-tiller power sources even more useful and beneficial to small-hill farmers.

Mini-tillers are part of the program of a women's micro finance group, Mahila Shayatra Microfinance Bittiya Sastha Ltd. The machines fit within the small-loan credit limits. Also, their small size allows women to operate them and opens up diversification of livelihoods for women farmers (Sumitra Manadhar Gurung, personal communication, 2013). While on a visit to this group in Makwanpur District the authors noted that one of the first users of the mini-tiller was an older couple (husband age 68 and wife age 58) whose children were working in Kathmandu. They were both operating the mini-tiller to plow their 0.66 hectares, suggesting that this small equipment might also address the problems of aging farm households.

In a new Agricultural Development Strategy document by the ADB, two issues are highlighted: (1) the importance of agriculture and rural mechanization and (2) renewed attention's being paid to the importance of irrigation, especially shallow tubewells in the Terai (see Tomecko and Poshan 2012; ADB 2011; Cook et al., 2012). However, because of the great range of farming conditions in Nepal, diverse irrigation technologies, including small-scale pumps and tanks, drip irrigation systems will be more effective ways to improve agricultural intensification in many situations, for example, areas of high-value crops with plastic tunnels and houses, where mini-tillers and other technologies are already spreading.

From a rural engineering perspective, micro hydro and other forms of engineering-based green energy sources are increasingly important in Nepal. In the hills and mountains water mills have for centuries been used for grinding grain, pressing oil, and so forth. Since the 1960 there have been many programs to improve water mills and small-scale hydro, and it is estimated there are now about 8,000 improved water mills, and more than 2,500 micro hydro-electric installations with installed capacity of 37

MW, from the smallest pico hydro of a few kilowatts to the mini hydro systems of up to 1 megawatt (AEPC 2011). The recent arrival in local hardware stores of Kathmandu of low-cost imports of micro and small scale hydro-electric turbines from China will probably lead to faster spread of smaller scale hydro-electric units.

Cambodia

Cambodia's national mechanization process stands out for many reasons. It is mostly a rural agrarian country in which more than 70 percent of the population earns a living from an agricultural subsector where the average holding is less than two hectares. Cambodia is also sparsely populated compared to other South and East Asian economies. However, it is estimated that there are nearly 3 million hectares of arable land uncultivated, of which nearly 2 million hectares have been leased out on long-term leases, in what some people term "land grabs," to various multinational corporations (Fighting land-grabs 2013). Many rural people are beginning to prosper due to the agricultural intensification through the spread of small-scale irrigation pump sets, 2WTs, 4WTs, and threshers that allow for the addition of dry season winter rice and other crops. Alongside this growing commercialized smallholder rural economy the large-scale corporate agricultural subsector has brought a parallel market for large tractors, planters, and other machinery. Although the government is attempting to provide support to both sectors, the demands by the larger corporate subsector are distracting from or diluting limited government resources from the needs of the smaller-scale rural economy.

Dynamic Alliance Consulting (2011) reports that agricultural mechanization has increased sixfold in Cambodia. Table 2.4 shows concomitant growth of the agricultural machinery sector. Once a net rice importing nation, Cambodia is now unofficially exporting 1 million to 2 million metric tons of unmilled rice to Vietnam and Thailand. This may soon change as the large investment in the auto rice milling industry in the past three years will allow for value addition and support a growing trend to market-milled Cambodian rice by Cambodians (WSJ 2013).

Table 2.4 Growth of farm machinery in Cambodia

Item	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Tractor	3,072	3,293	3,310	3,857	4,166	4,247	4,475	4,461	5,495	5,893
Tiller	8,789	9,782	13,693	20,279	26,504	29,706	34,639	38,912	54,163	60,941
Harvester	-	-	-	-	-	395	395	430	836	859
Thresher	3,780	4,199	4,967	6,220	7,338	7,795	8,036	8,237	13,798	14,262
Engine pump	64,406	82,622	99,875	106,569	120,968	127,610	131,702	136,061	164,482	167,152

Source: Table taken from Dynamic Alliance Consulting (2011) report illustrating the growth of farm machinery in Cambodia.
Note: Tiller = Thai two-wheel tractor. Dashes indicate that data is not available.

Afghanistan

Afghanistan has perhaps one of the shortest histories of smaller engines and smaller equipment.[14] Agricultural mechanization in Afghanistan was influenced by the former Soviet regime's collective ideals of large-scale machinery. Similarly, Pakistani influences have been mostly of the Punjab large-scale machinery type. Indeed, with an impending United States Agency for International Development (USAID)–sponsored 2WT dissemination project looming in 2009, project staff were inundated with complaints from the Department of Agriculture that were premised by, "We are a 4WT nation and these 2WTs will never sell." However, shortly thereafter, more than 4,000 2WTs with plows,

[14] This section is based on the personal experiences of one of the authors working in Afghanistan in four mechanization projects from 2005 to 2011.

reapers/harvesters, seed drills, and trailers were sold, albeit with a generous USAID-supplied 60 percent copay[15] within a nine-month period.

Interesting to note, another USAID Afghanistan Vouchers for Increased Production in Agriculture South project intended to distribute 15,000 small-horsepower Chinese diesel pump sets to farmers along the Helmond River. However, the provincial governor feared a water war would erupt, with river tail enders getting even less water, and stopped the project. Notwithstanding this, during the past ten years large numbers of small-horsepower Chinese single-cylinder diesel engines have been imported and sold for generating electricity for irrigation pumping and threshing. A rough estimate would put the number of 2WTs in 2013 in Afghanistan at 9,000 and small pump sets at 30,000.

Bhutan

It is estimated that there are more than 3,000 2WT in Bhutan, which were introduced under a long-standing Japanese aid program. Bhutan is interesting in that from early 2004 there has been a funded power tiller "track" program to build narrow, lower-cost tracks in rural areas to increase accessibility for 2WTs. In a mountainous country, where the cost for investment in and maintenance of wider, hard-top roads is high, narrower and less engineered green roads are seen as a viable transport and rural development initiative (Tobgay and McCullough 2008).

[15] Today, "farmer copay" and "vouchers" have become substitute terms for "subsidy" among many unilateral and multilateral donors.

3. OBSERVATIONS

The brief and select histories of the spread of smaller-scale equipment in the preceding section illustrate the diversity of rural mechanization processes that have taken place. In this section, we draw out some general observations to provide a background for the discussion of the themes.

General Observation 1: Long Histories and Mixed Heritage of Smaller-scale Engines

In South and Southeast Asia there are diverse patterns of rural, smaller-scale mechanization.[16] Many of these have long histories going back to the 1960s, and some other countries and regions, such as Afghanistan, Myanmar, and Bihar, have only recently seen the more rapid spread of smaller-scale diesel engines. The history of imports and local manufacture is also varied, as is the sequencing of operations that mechanized before others. In Bangladesh, clearly small pumps for irrigation came before 2WTs. In Northeast Thailand it was the spread of 2WTs in rainfed agriculture that led to increased rural development. In Bangladesh, Vietnam, and parts of Thailand, the use of smaller-scale engines with boats and shrimp-tailed propeller pumps formed the major part of the history. In many of the countries, the use of smaller-scale engines for transport (by water and on land) as well as agricultural purposes was a central feature in understanding their spread.

As we mentioned at the start of this paper, we are not looking at the spread of larger-scale equipment, such as 4WTs, large combines, harvesters, large-scale deep tubewells, and large-scale rice-milling equipment or at the engineering of large-scale canal systems. This is not because a historical analysis of rural mechanization would need an analysis of the overall relationships between the different scales of technology. Rather, it is because this paper is concerned with the histories and lessons coming from smaller-scale rural mechanization that are often neglected in some global and national rural mechanization policy debates.

In summary, the lessons from these histories are the following:

- Long histories of substantial smaller-scale rural mechanization, for example, Vietnam, Bangladesh, Sri Lanka, Thailand, and parts of India and more recently spreading in Bihar, Nepal, Afghanistan, and Bhutan[17]
- Diverse patterns of rural mechanization
- Increasing diversity of models and sizes of machinery and their sources of fuel (diesel, electric, petrol, kerosene, compressed natural gas [CNG], and now solar sources)
- Different sequences in the mechanization of rural and agricultural operations
- The importance of the use of tractors and other engines for transport

General Observation 2: Multiple Uses of Smaller Engines and Multiple Markets for Engine Services

The second observation concerns the multiple uses and diversity of market institutions for the services of smaller-scale engines. Not only have small-scale engines been used for many purposes, such as powering boats, pumping water, milling, hulling, threshing, processing agricultural products, and powering 2WTs, but the same engine has been put to multiple uses. For example, a 2WT of the Kathmandu and Pokhara Valleys is generally used for transport, tillage, and other rural operations as well as for the transport of construction and other goods in the local coterminous urban areas. In Sri Lanka, 2WTs are used a great

[16] Recently, Diao et al. (2014) have taken illustrative representations of different patterns of agricultural mechanization in China, Bangladesh, and India to illustrate the importance of considering alternative institutional models in policy analysis in Ghana.

[17] In this paper we do not look at China, where, as illustrated in Table 2.2 it can be seen that the number of 2 wheel tractors is huge.

deal as taxis or buses as well as for agricultural purposes. In Nepal, pump set engines are widely used to power threshers.[18]

Alongside the spread of smaller-scale engines and other smaller-scale equipment has been the spread of a great range of market institutions for the buying and selling of services. In Bangladesh, the markets in water and 2WT services have long been documented by Mandal (2000) for 2WTs in Sri Lanka (Biggs, Kelly, and Balasuriya 1993) and Thailand (Grandstaff et al. 2008). In the Kosi region of Bihar, the spread of bamboo tubewells was facilitated by rural entrepreneurs who sold pumping services from a heavy Indian diesel pump set mounted on bullock carts (Appu 1974). As a result of the remunerative benefits of 2WTs custom service markets in Nepal, some have had a long life. Indeed, some of the original Japanese and Korean 2WTs are still operating and providing their owners income after 30 years. Notwithstanding this, the general payback period on total investment for a Chinese 2WT in Nepal and Bangladesh has, and continues to be very good, generally less than 2 years.

General Observation 3: "Good Enough," Profitable Equipment with Smaller Engines Is Owned by Rural Entrepreneurs

The third observation is that it was good enough equipment, owned by rural entrepreneurs, that has spread. In the overall picture, the light, single-cylinder diesel Chinese engine played a major role. Before the imports of Chinese equipment to Nepal, the Japanese and Korean 2WTs proved to be robust over the long term with some still in operation in the Kathmandu Valley. We use the term "good enough"[19] to highlight the issue of who sets the standards for the manufacture /import of equipment, its promotion, or both. The Bangladesh case illustrates how technical standards set by the relevant government authority prevented the importation of 2WTs from China. When the government lifted the restriction, importation of equipment expanded rapidly. However, the change came after five to ten years of government, donors, and nongovernmental organizations' (NGOs') formal and informal experimentation with different types of equipment and institutions. The paradox of India's low numbers of 2WTs is brought out again in this regard. India has also set up technology vetting centers in Madhya Pradesh, Haryana, Andhar Pradesh, and Assam through which the manufacturers and importers must pass to participate in the large government agromachinery subsidy program. There is also evidence that this long-term subsidy program has driven up the prices for farmers who cannot participate in the subsidy scheme due to limited size of the scheme. As we saw in Table 2.3, of the total number of 2WTs in India, Bangladesh, and Nepal, the majority were in Bangladesh (2.5 percent), with only 1.5 percent in the whole of India. This picture is now changing as it is estimated that about 55,000 2WTs per year are being sold in India and nearly 35 percent of this total is imported from China by Indian companies.

The second point to note is that the smaller-scale equipment is owned by rural entrepreneurs and is highly profitable. This is illustrated by 2WTs. In Bangladesh, Nepal, Sri Lanka, and Thailand, they are owned by people who may have some land, but generally their services are hired out to others for multiple purposes. Transportation is the most common nonfarm use. However, applying the "nonfarm" label to transport and other activities is problematic. In the places where smaller-scale engines have spread, the engines are used as much for nonfarm use as for farm use, and it is this flexibility that has made them attractive to rural entrepreneurs as an investment.[20] There are numerous studies of the use and

[18] Interesting to note, in Nepal the engines of traditional larger-scale combine harvesters often remain unused outside of the harvest season. Apparently, investment decisions are such that for those who own such large engines, it is unnecessary to utilize the engine more fully as a power source for other operations. However, even this practice is now changing with four-wheel tractors (4WTs) being used on combine harvester equipment to provide the power source.

[19] We first came across this term in Qiuqiong, Rozelle, and Hu (2007), who use the term in describing the smaller-horsepower Chinese electric motor industry used in irrigation and other rural and agricultural mechanization processes.

[20] This applies even more so to the larger four-wheel "agricultural" tractor, which, for example, on the Indian and Nepal Terai (Gangetic plains), in the mid and high hills of Nepal, and in parts of Bangladesh is primarily used for transport purposes of diverse goods.

markets of services of smaller-scale equipment and their profitability.[21] In a recent study in Bangladesh[22] it was found that the time to recover full investment costs in shallow tubewells, 2WTs, and power threshers was 2.5, 1.8, and 1.5 years, respectively. The same survey shows that funds for investments in shallow tubewells, power tillers, and power thresher come mainly from investors' own savings, family, and so forth rather than from bank loans. In recent years the source of loans, especially from friends and relatives, has grown. Some of this own savings may well be coming from remittances of laborers from rural areas working in the Middle East and other countries. The same recent Bangladesh study showed that more than 90 percent of farmers who own 2WTs hire them out, and 25 percent or more of farmer/owners hire out their shallow tubewells and power threshers. In some policy and technology discussions, the idea is introduced that smaller-scale equipment is for multiple use on self-contained small farms that have little contact with outside local markets. The Asian data clearly show that this representation of a small farm agrarian/rural economy is incorrect.

In many situations the equipment is operated by paid laborers who are also responsible for renting out the machinery on a daily or monthly basis. These 2WT operators generally do not have access to savings and loans by which they can buy and operate their own machinery. In Nepal, becoming a 2WT operator is seen by some laborers as a route to a better-paid, more lucrative and respected bus or truck driver jobs[23].

General Observation 4: Energy Policy Has Been a Central Component—Availability and Prices of Electricity and Fossil Fuels

Table 3.1 graphically illustrates that different countries have different sources of energy and energy policies. For example, in India 25 percent of the horsepower in agriculture comes from electric engines, whereas in Bangladesh and Nepal it is only 6 percent and 11 percent, respectively. Two-wheeled tractors have been powered by diesel. The power source for irrigation pump sets has been more diverse, including electricity, diesel, petrol, and kerosene. In Bangladesh, shallow tubewells and low-lift pumps have been powered mainly by diesel fuel.[24] As an overall observation, it would seem that smaller-scale shallow tubewells have spread more rapidly where diesel/petrol pump sets have been available and promoted. In some situations, the unreliability of electricity is a well-known problem, which can be costly for cultivators. The lack of the availability and promotion of lighter-weight and inexpensive Chinese diesel-powered pump sets and 2WTs in Eastern India could be some of the explanation for the slower growth of the agricultural sector and other parts of the rural economy. That now is changing with the increased spread of smaller-scale equipment, some of which in earlier days used to come over the borders from Bangladesh and Nepal. Interesting to note, a Bangladesh policy to promote the use of CNG from its own supplies for use in domestic vehicles has not led to the spread of CNG for powering these engines in rural and agricultural areas. This may be because CNG is less available in the rural areas and that the appliances needed to convert these rural engines to CNG have not been developed. However, as a result of the policy, imported diesel is freed up for use in rural areas.

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[21] See, for example, Biggs (2012), Grandstaff et al. (2008) and Biggs et al. (1993), Appu, (1974), Alam et al. (2004).

[22] See Hossain et al. (2013).

[23] For details of the ways these 2WTs and service markets have been operating in Bangladesh for many years see Alam et al. (2004) and International Development Enterprises (2012).

[23] Obtaining credit from the formal banking system by poorer rural people is notoriously difficult in most countries, even in Bangladesh with its long history of micro finance. However, a new credit program with refinance by the Central Bank of Bangladesh was started in 2009. It was based on the rationale: "Due to the ineffectiveness of conventional micro-credit and formal banking systems to reach agricultural credit to marginal and small farmers who dominate the agrarian structure in Bangladesh" (BRAC 2012). In Nepal in 2004, the Poverty Alleviation Fund was prepared to refinance loans for 2WT and other smaller-scale equipment to poorer rural households. However, Nepal banks were not prepared to move into this work. A new bank, Mahila Sahayatra Micro Finance, started in 2012 and now has provisions to make loans for equipment to poorer rural entrepreneurs without land or other assets.

[24] The diversity of energy policies within countries also affects the supply and use of power. For example, different states of India have different policies for the supply and pricing of electricity (Mukherji, Shah, and Verma 2009).

Table 3.1 Composition of mechanical horsepower by engine size: Bangladesh, India, Nepal, estimates for 2012

	Bangladesh			India			Nepal		
Energy source	Number of units	Total horsepower	% of total horsepower	Number of units	Total horsepower	% of total horsepower	Number of units	Total horsepower	% of total horsepower
Two-wheel tractors[a]	500,000	7,500,000	53	300,000	4,500,000	2	16,000	240,000	13
Four-wheel tractors[b]	35,000	460,000	3	3,500,000	122,500,000	56	30,000	900,000	51
Irrigation shallow tubewell pump—diesel[c]	1,200,000	6,000,000	42	9,000,000	45,000,000	20	120,000	600,000	34
Irrigation pump sets—electric[d]	100,000	200,000	1	12,000,000	48,000,000	22	10,000	40,000	2
Total		14,160,000	100		220,000,000	100		1,780,000	100

Source: Authors estimates

Note: Estimates of the numbers of power sources (and their horsepower ratings) are used primarily in agricultural and processing uses, including groundwater irrigation pumps. Estimates do not, for example, include the many engines used in Bangladesh to power riverboats, rice mills, processing, and so forth, although these are a major part of the Bangladesh agriculture and rural economy. [a] Average of 14 horsepower per two-wheel tractor. [b] Average of 30 horsepower per four-wheel tractor. [c] Diesel/petrol irrigation pump sets are average 5 horsepower; 5–10 percent of the pump sets are petrol/kerosene. [d] Average electric tubewell is 4 horsepower.

Nepal's underdeveloped hydroelectricity potential has also directly affected choice of technique as regards electric or diesel engines for pump sets. This might be beginning to change now for a number of reasons: (1) more decentralized electricity user groups whereby electricity is sold in bulk to user groups and (2) the spread of smaller-scale hydroelectricity plants with increased attention given to the use of electricity for economically productive purposes, such as local irrigation, processing, and other rural economic activities.

Table 3.1 also shows that India has the highest usage of electricity at the farm level. The large and mostly state-funded electricity subsidies have led to high levels of usage by farmers, especially for irrigation. This also has led to the well-known unsustainable mining of the aquifers in the drier, and more affluent, northwest (Gupta et al. 2003)

General Observation 5: The Importance of Informal R&D

In many of these histories, informal R&D has been important, if not central, to understanding the spread of the smaller-scale technology. In the case of Vietnam, the use of the small engine came about because a local engineer saw the potential of changing the use of the equipment for power boats and axial flow pumps (Biggs 2012; Sansom 1969). Similarly, in Bangladesh local engineers and artisans modified and adapted the Chinese engine for different purposes from those for which they were initially introduced. The spread of bamboo tubewells in the Kosi region of Bihar was a classic and well-documented example of where a government tubewell package was unpacked. The diesel pump set was then mounted on a bullock cart to sell pumping services to farmers who had cheap bamboo wells sunk on their own fragmented plots. Innovation also took place on the institutional level in the creation of local markets in services. An example of an institutional innovator was a local administrator who went against the grain and created a local government program to promote the spread of irrigation through this new technology (Appu 1974). More recently, the efficiency of shallow tubewells has been improved by the spread of inexpensive plastic lay-flat pipes[25] in Nepal and elsewhere (de Bont 2014). These flexible delivery hoses originated in the black plastic pipe extrusion industries in South Asia (Figure 3.1).

Figure 3.1 Simple, inexpensive, locally produced via plastic extrusion, lay-flat flexible hose pipe

Source: Scott Justice (2004).

[25] Lay-flat pipes are made of cheap, locally produced plastic flexible hose pipe that enables water to be pumped to specific fields where and when wanted; in doing so, the pipes address a whole range of ownership, timeliness, small plot, and fragmented plot problems. Lay-flat pipes reduce conveyance losses (> 20 percent water savings), reduce labor as there is no need for tertiary ditches, allow movement of water over or under previously impassable obstacles, reduce conflicts as traditionally moving of water near or through neighbors' fields was a potential source of conflict, and even increase yields via better "in-field" water management.

The lay-flat pipes rapidly became so common that in some areas local people do not even see them as being new or unusual. More recently, Pearce (2012) reported that in India ice pop wrappers are now being used for drip irrigation at a cost far below the more conventional designs coming from the market or more formal R&D programs. In these cases, informal R&D has proved itself an important source of innovation for the management of irrigation water.

In Bangladesh, the 2WT reduced or zero-till drill that was promoted by the International Maize and Wheat Improvement Center in the late 1990s and early 2000s for wheat and other grains spread quickly, not for reduced till wheat but as a high-speed rotovator tiller used for onion and other high-value crops. According to International Development Enterprises (2012), by 2012 their numbers had grown to more than 2,000 pieces, and importers were actively marketing them as high-speed rototillers. In all these situations, local innovators have transferred materials and equipment from one part/sector of the economy to another to create new techniques/institutions.

General Observation 6: The Political Economy of Agrarian and Rural Change in a Broader Context

The final observation concerns broader political economy, trade, and development issues. In this brief illustrative review, we have not looked at gender, caste, income distribution dimensions of the spread of smaller-scale equipment, as that has been beyond the scope of this paper. However, we suspect that the spread of smaller equipment is more equitable than that of larger equipment. Such an analysis would require a different review of evidence and analysis. We also have not looked at the health and safety dimensions of the spread of this type of equipment. Accidents due to machinery are notoriously high in agriculture and rural industries and the rural transport sectors in most countries, especially among laborers and poorer farmers and rural entrepreneurs. This is another issue that requires further research. Even when regulations and standards are present, effective health and safety practices do not appear to be a major concern of practitioners involved in rural mechanization R&D, promotion, and effective private-sector or public-sector monitoring and enforcement.

The most important political economy observation is that the spread of smaller-scale equipment in rural areas of some South Asian countries cannot be understood without looking at the structure of the agricultural and the broader rural and national economy. Factors that need to be considered are (1) the relationship of the rural economy to the rest of the economy, (2) trade regimes, (3) the extent of migration, and (4) whether the country is in a conflict or a post conflict situation. We conclude that much of the literature concerning agricultural and rural mechanization, agrarian and rural change, and choice of technique has often overlooked the significance of these broader issues and as a result has presented only partial and sometimes unhelpful conclusions. The continuation of such partial analysis is particularly problematic now when dimensions of rural mechanization are central to policy debates on food production and security, ownership and management of land, rural equipment, land grab debates, and rural employment and migration. Any discussions concerning the implications of different patterns of land ownership will not move the debate forward unless they contextualize rural mechanization choices within national and global settings.

4. EXPANDING THE POLICY DEBATES

Some readers may be frustrated that we have given minimal detail in our observations about the spread of different patterns of smaller-scale rural mechanization in some other South Asian countries during the past 60 years.[26] We trust that more detailed analysis will provide support and nuance to our general observations. We now move to themes that need to be addressed if policy debates are to be further opened up. We say "further opened up" because many Asian countries in recent years have seen substantial growth in their rural and agricultural economies. Even the most enthusiastic proponents of large-scale commercial agriculture will be hard pressed not to see the connection between productivity increases in smaller-scale agriculture and the spread of smaller equipment.[27] We feel the policy debates are being opened up now, not because academics and centers of global policy analysis on agriculture and food have led the way but rather because global events have demanded attention be given to these issues. Events such as food riots, land grabs, and the associated promotion of large-scale mechanization equipment, scarcity of water and energy, emerging remittance economies, and global trade in intermediate goods.[28] These emerging issues are slowly bringing rural mechanization issues to the fore of global economic policy debates. However, before discussing ways forward in policy we need to look at some themes that have characterized this area of policy discussion in the past and which, if not adequately addressed now, will, in our view, continue to bias policy discourses in the future.

Theme 1: Missing Histories: Why Have the "Silent" Revolutions Not Been Seen or Heard about Earlier?

In recent literature references have been made to the spread of smaller-scale engines and associated equipment. Pearce (2012) remarked on the "hidden farmer-led revolution," and Giordano et al. (2012) wrote about small-scale irrigation technologies' being a "new" dynamic.

Therefore, we cannot but ask the question, Why have these revolutions been silent and below the radar, and why have they not informed national and international policy debates? The recent Vietnam history by David Biggs (2012) documents well how smaller engines have been spreading rapidly since the mid-1960s. In Bangladesh, the spread has been taking place since the mid-1980s and has been well documented for years. Other writers observed that different Green Revolutions of South Asia were brought about by the spread of smaller-scale irrigation and other rural equipment.[29] As early as the mid-1970s, the senior Indian administrator Appu (1974) wrote an article for the widely read journal *Economic and Political Weekly* titled "The Bamboo Tubewell: A Low Cost Device for Exploiting Ground Water." The article contained many if not most of the lessons that are now being seen as part of the new and silent revolutions.[30] In Bangladesh, where it is estimated that more than 80 percent of tillage operations are mechanized, most of this has been done for many years by 2WTs, where rural entrepreneurs own the 2WTs and hire out the tillage custom services (Alam et al. 2004); Hossain et al. 2013) So the question remains, Why has this evidence not been recognized? Although the economies of some regions of South Asia have been experiencing these changes, and the evidence has been documented and well recorded, in

[26] That said, the former United Nations' Asian and Pacific Centre for Agricultural Engineering and Machinery (UNAPCAEM)'s website, now called Center for Sustainable Agricultural Mechanization, has a small treasure trove of presentations and reports waiting to be mined on various aspects of agricultural mechanization by senior agricultural engineers from many member countries dating from the past ten years. The documents can be found at http://un-csam.org/cp_index.htm.

[27] In an earlier article, we argued that these bigger debates on rural mechanization needed to be opened up, having been closed down since the 1970s (Biggs, Justice, and Lewis 2011).

[28] Examples include 2WTs and their attachments, diesel pump sets, electric motors of all sizes, and a whole range of renewable energy technologies. Also see Agyei-Holmes (2014).

[29] For example, see Molle, Shah, and Barker (2003); Mandal (2011); Rigg (2003); and Barker, Herdt, and Rose (1985); Shah, 1993; Shah et al., 2000; Kikuchi et al., 2003; Sikka and Bhatnager, 2005.

[30] See Mukherji, Shah, and Verma (2009) and Pearce (2012). The question comes up again: why were lessons from Bangladesh, which were apparently relevant to India, not recognized earlier, when substantial empirical evidence was well documented since the 1980s and early 1990s?

some circles these changes are now being treated as new and previously hidden. In some policy debates and agricultural and rural mechanization R&D projects in different African countries there is sometimes little reference to these Asian experiences of the spread of small engines and custom markets (Biggs and Justice 2015).[31] There are many explanations to our rhetorical question, and we will explore some possible answers here. We argue that unless the reasons for past and ongoing behavior are explored, then at best we are likely to come up with ineffectual policy rhetoric and practice in the future.

Theme 2: Characterization of Small-scale Machinery

Biases in Official Data Reporting

Until recently, the Food and Agriculture Organization of the United Nations only counted 4WTs as "tractors." 2WTs, if included, were often referred to separately as hand tractors, pedestrian tractors, power tillers, and garden tillers and did not count as "tractors." The same thing has happened in national data systems. This bias in official data collection procedures has helped to keep the spread of smaller-scale equipment out of sight. At the current time, with the spread of even more powerful 2WTs with engines in the 20+ horsepower range, and with 4WTs with engines of less than 15 horsepower spreading, there is clearly a need to look closely at official data collection methods.[32]

There is also a problem of under recognition of the spread of smaller-scale engines when they are used wholly or partially for "nonagricultural" purposes, such as for low-lift irrigation pumps, shallow tubewells, river boats, transport, milling, processing, forestry, and other rural activities (Steele 2011).

Mischaracterized

Another problem with the official data collection is the mischaracterization of the importance of the spread of smaller-scale equipment. Smaller scale is sometimes seen as the continuation and expansion of "traditional" equipment, where traditional is seen in a derogatory sense, and smaller-scale machinery is seen as a "transitional" stage to larger, that is, modern, large-scale mechanization. Therefore, the smaller-scale equipment, even if useful for a while, does not count. The notion of smaller-scale machinery as merely transitional does not track with the experience from Southeast Asia and China. Even with the rapid growth and spread of 4WTs, the 2WT industry continues to grow, albeit at a slower pace in Thailand (Thepent 2011) and China (Wang 2008).

Misunderstood, Misreported, and Misrepresented

One of our best examples of the misreading of smaller-scale mechanization at the moment is the spread of lay-flat irrigation pipes in South and East Asia. This widely used and inexpensive technology may well be one of the most important innovations in irrigation technology in the past 15 years. Where it is common, it is treated as if it has always been present. However, in both Nepal and Bangladesh, we find there are few articles written about it or programs to promote its spread in regions where it is not common.

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[31] Two notable exceptions to this are the Farm Mechanization and Conservation Agriculture for Sustainable Intensification project (FACASI), where concentration is on small engines and custom service markets, and the policy debates in Ghana (Diao et al. 2014).

[32] Clearly, organizations like FAO know there have been data collection problems, and there is a need to assess current rural mechanization issues. This was one of the rationales for an FAO agricultural project to review these issues in 2009. The book has now been published (Kienzle, Ashburner, and Sims 2013). At the time Peter Steele wrote a report ("Agro-mechanization and the Information Services Provided by FAOSTAT") specifically on the data collection, reporting, and analysis issue (Steele 2011). In 2011, FAO and the UN Asian and Pacific Centre for Agricultural Engineering and Mechanization started preparing a report titled Status and Future Strategy of Sustainable Agricultural Mechanization in Asia and the Pacific. This is a challenging and important project in a rapidly changing global economy. It is hoped that the country studies and global analyses will be available soon and cover, in addition to technical issues, an economic, social, and political analysis concerning the relationship of different patterns of rural mechanization to such national economic goals as rural development, food sovereignty, rural employment, trade, energy, and the environment.

Furthermore, there are plenty of examples of pockets of resistance that still exist in some universities and in policy discussions that either deny its existence or trivialize its importance.

Another example of misrepresentation is when 2WTs are presented as if they have no more than 5 to 8 horsepower, when in fact the 2WT engine can be of 20 or more horsepower—larger than many of the small Indian 4WTs like Captain Tractors and even the 16-horsepower Yuvraj models from Mahindra and Mahindra.

In some discussions of tubewell and low-lift pumps, there is a misunderstanding of the differences between centrifugal and axil flow pumps, and between shrimp-tailed propeller pumps and axial flow propellers (they are the same). Care is not always taken to distinguish lift levels in axil flow discussions or whether the discussion concerns electric, diesel, or petrol engines for pump sets.

Minor Status in Policy Debates

Smaller-scale mechanization is often relegated to a minor and inferior status in irrigation policy discussions and in the institutional setups of government structures. For example, the term “minor” irrigation is used to describe smaller-scale groundwater and low-lift pump irrigation when in fact the smaller-scale equipment might be the most important and carefully managed source of irrigation water. This is true for both Nepal and Bangladesh where shallow tubewells and pump sets come under the lightly funded Minor Irrigation Divisions of the Departments of Irrigation. In large canal irrigation situations where conjunctive use of water is expected, the main canal management often takes priority over the smaller-scale equipment, such as low-lift pumps from the canal or groundwater shallow tubewell irrigation, which might be useful in the same area.

Often, “appropriate,” “intermediate,” and “alternative” technology institutions and activities are not part of mainstream technology policy discourses. Labeling some technologies in this way has been a method for excluding some technical choices from policy consideration.

Misplaced Authoritative Knowledge

Finally, we need to mention the problem of misplaced authoritative knowledge, for example, where Bangladesh and Nepal officials are not aware, or deny the importance, of lay-flat irrigation pipes or where technical consultants and professional staff of aid agencies have little relevant knowledge. These are general issues that are well discussed in the aid literature and are not our focus here. However, in the case of the spread of smaller-scale irrigation equipment and 2WTs, we have seen that the plans and strategies of aid projects have not been informed by long experiences in South Asia where this type of equipment has spread. For example, in mid-1990s Nepal, the Agricultural Perspective Plan, drawn up with support of the ADB explicitly excluded consideration of any motorized rural mechanization. Even today, some aid agency staff and consultants appear to be unaware of South Asian experiences and knowledge concerning smaller-scale equipment. As recently as 2012, there was almost disbelief among senior agricultural aid officials when we suggested that more than 80 percent of all tillage operations were mechanized in Bangladesh, and this was mainly by 2WTs.

Theme 3: Biases for the Promotion of Larger-scale Equipment

There is a whole range of arguments—often unsubstantiated—that is biased toward larger-scale equipment.

Claims of Efficiency: Engineering Efficiency in Large-scale Agriculture

In any analysis, it is difficult to factor out the “technical” efficiency of larger-scale operations from the benefits due to subsidies, influence, knowledge, and power in markets, whether this be through lobbying power or access to latest information. In addition, large-scale agriculture might appear technically and economically efficient, but the assessments change when sustainability of the long-term use of resources and other positive and negative externalities are taken into consideration.

Size of Holding

Academic debates on the efficiency of different size holdings have a long history and were the center of much discussion in the 1970s. Some of those debates concerned the rationale for institutional reforms in rural areas, such as distributive land reforms, land ceiling acts, and measures to support less powerful rural people who could not have access to credit, markets, and relevant technical information. Although most information supported the idea that smaller holdings were more efficient than larger holdings, unsubstantiated claims persist for the technical efficiency of larger-scale equipment.

Assertions that Productivity in Rural Areas Can Be Increased Only with Larger Holding Size, Land Consolidation, or Both

It is difficult to understand the almost universal mantra in some policy circles and technical consultancy reports that small holding size and fragmented plots are central problems. Indeed, the notion runs in the face of the national empirical evidence of Bangladesh where agricultural productivity has been steadily increasing as size of holding has been decreasing. In 1983/1984, the number of marginal farms with less than 0.5 acres was 2.4 million, and in 2008 this had risen to 4.1 million holdings. The number of farms with more than 7.5 acres dropped from 0.5 million in 1983/1984 to 0.2 million in 2008. During the same period, average farm size dropped from 2.00 acres to 1.26 acres (Mandal 2011). The smallholder agriculture of other regions, where smaller-scale equipment has spread, also has seen increases in productivity.

The Punjabi model of the Green Revolution, characterized by the spread of high-yielding varieties and the use of 4WTs in the 30- to 70-horsepower range, irrigated by large canal irrigation or large highly subsidized deep tubewells, and harvested by large combine harvesters, is still promoted by many as representing the only Green Revolution model. David Biggs (2012) reported that in Vietnam in the 1960s, American agricultural advisors were preoccupied with the promotion of the US family farm and the 4WT model of agriculture. The experiences of Bangladesh, Vietnam, Thailand, and Sri Lanka show that there are many types of Green Revolutions as regards patterns and scales of rural machination.[33]

In a recent study from the International Food Policy Research Institute (Zhang, Yang, and Reardon 2015), the authors argue that past and current academic advocates of larger holdings (Pingali 2007; Ruttan 2001) do not take sufficient account of opportunities and evidence arising from custom markets in rural mechanization processes. We argue that, in addition to service provision from large combine harvester service providers (their case study), there also has been a neglect of analysis of the widespread markets of service provision from small farmers and other small scale rural entrepreneurs selling services from smaller engines.

Global Reports on Future Food and Agriculture

Another source of bias against smaller-scale equipment comes from media presentation of global food and agriculture. Even when small-scale agriculture is included in the discussion, the report is often accompanied by photographs of fleets of combine harvesters and seeders drawn by large 4WTs working across large, flat landscapes. Rarely do we see pictures of smaller-scale mechanization of the type we have been discussing here. It is hardly surprising that some policy discourse is informed mainly by such information.

[33] See Harwood (2012) for a recent history of different Green Revolutions that goes back to some of the early European experiences. In this paper we do not include an analysis of the Chinese history and contemporary situation and refer readers to such works as Yang, et al. 2013, Zhang et al. 2015, Wang 2008 and 2013.

Multinational Corporation Activities

Another source of bias toward larger equipment is multinational corporations in search of markets for their products.[34] Often these large institutions have the position and power to advertise, provide information, provide credit, and lobby for their interests. Sometimes they invoke the arguments of efficiency and suggest that "their way is the only way." As can be seen in the earlier mentioned Afghanistan example, often senior agricultural leaders and planners in ministries and departments view modern agriculture in terms of large-scale equipment and thus are sympathetic to the vision promoted by the multinationals.[35] The pairing of multinationals and policymakers in the agriculture sector has a long history that persists today. For example, in Nepal, multinational companies continue to open up sales and promotion offices at the same time that the Agricultural Engineering Division of the Nepal Agricultural Research Institute and Agricultural Engineering Directorate in Nepal's Department of Agriculture are marshaling their few resources in an effort to obtain and promote machinery that is more relevant to the smaller holdings of much of Nepal. Even though 2WTs account for most of the tillage operations in Bangladesh, there are yet again moves to subsidize and find public-sector support for 4WTs there.[36] We are not suggesting that larger equipment does not have a place, but the current lobbying and promotion on the part of the multinationals needs to be weighed up against past empirical evidence and information from other sources.

Research and Teaching in Engineering Departments Biased toward Larger Equipment

The ideals and aspirations for future mechanization encountered in engineering and agricultural research and teaching departments often mirror the biases of the government agriculture/irrigation agencies' leaders mentioned above. Although a comprehensive review of this issue is beyond the scope of this paper, the research and training of engineers has an important influence on rural mechanization policy and practice. The influence of professional training goes beyond national agriculture institutes into the international agricultural research centers and donor agencies. Interesting to note, while financial and professional rewards have been more associated with the promotion of larger equipment, the major spread of the highly successful smaller-scale equipment appears to have come about in some South Asian countries without much support or inputs from formal engineering departments.

Theme 4: The Promotion of Simplistic and Often Unempirically Based Institutional Models for Smaller-scale Machinery

The last theme concerns the promotion of simplistic institutional models in association with different types of equipment. For example, to benefit from economies of scale, governments or other promotional organizations encourage the formation of rural self-management groups or cooperatives, often with a 50 percent subsidy on the capital cost. Groups are sometimes recommended because fragmented or smaller holdings are seen as a problem. Shallow tubewell groups are a good example of such a model. They have the additional problem that cooperative assistance has a feel good factor over providing assistance for shallow tubewells and pumps to individual farmers. On other occasions, government or cooperative tractor hire schemes are recommended. The problem we see here is that these types of institutional

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[34] See AgriEvolution 4th World Summit on Agricultural Mechanization, December 5–6, 2013, Federation House New Delhi (http://www.cema-agri.org/event/agrievolution-4th-world-summit-agricultural-machinery; last accessed April 29, 2014). The event was hosted by FICCI (Federation of Indian Chambers of Commerce and Industry), where many major agricultural machinery multinational corporations such as AGCO, CNH International, Mahindra and Mahindara, and other Western agricultural organizations from around the world discussed trends they would like to see in developing countries.

[35] A recent study of the promotional activities of international agricultural machinery corporations and the dilemmas faced by local policy analysts is well described in Agyei-Holmes (2014).

[36] International Development Enterprises (2012) shows that although the smaller 2WTs give a total repayment on investment in less than two years, various members of the 4WT lobby are expecting investment cost subsidies and other types of support such as special bank loans. It may be that some large holdings want 4WTs, but it is hard to make a national policy case for subsidies for larger-scale equipment.

models are extremely difficult to implement unless the broader social/political structural contextual issues are adequately addressed at the same time. Elite capture and bad management are frequent outcomes of past activities. By the same token, the advocacy that free market institutional models are the way to go is equally simplistic and does not take into account that the playing field for poorer people generally is not level as regards access to information about equipment, credit, or advice. Our point is that in the promotion of equipment to benefit poorer people, the policy discourse is often full of simplistic institutional models, with little reference to the way smaller equipment has spread in the past. Much of the experience of the spread of smaller-scale equipment in South Asia indicates that economies of scale issue were addressed in institutional models where markets in services have been encouraged. It is almost as if tractors and pump sets, large or small, will miraculously appear, be maintained, and even be locally produced, and cooperation and coordination between energy and irrigation ministries can be achieved, through regular coordination meetings. We suggest that there is a simplistic engineering bias underlying rural engineering policy discussions on relevant institutional models at the micro and macro level. The engineering bias is generally a greater problem for the encouragement and promotion of smaller-scale equipment, and relevant and viable institutional models, than it is for privately owned large-scale equipment.

5. WAYS FORWARD IN POLICY ANALYSIS

Topic 1: Recognition of the Centrality of Local Conditions

Our first lesson is the need to recognize the centrality of local, time-specific conditions at the micro field/village level and at the policy macro level. Simplistic generalizations for the scaling out and scaling up of techniques and institutional models, while often part of many policy/project initiatives, are not based on the experiences of the spread of smaller equipment in some Asian countries.

Our own field-level experiences of the diversity of local soil and water management situations in Bangladesh and Nepal make this lesson apparent. If one adds to this the complexities of agrarian structure, cultures, migrant activities, social position, and economic situations, it becomes clear that the analysis of local conditions is central to serious policy discourse. At the macro level, Bangladesh with its gas reserves is in a different situation from Nepal with its underutilized hydroelectricity potential. India's energy policy concerning support for different patterns of electric (coal) and diesel engines for groundwater irrigation is a local issue for the India government. In Bangladesh the presence or lack of presence of arsenic and other groundwater quality issues is a localized problem at the national, regional, and local levels. Suitable legislation concerning the use and maintenance of groundwater aquifers is an especially important area of regulation—whatever smaller- or larger-scale tubewell equipment is involved. The historical context is also important. For example, the histories of subsidizing richer and/or poorer cultivators in poor rural areas affects expectations regarding future subsidies. Institutions and policy practice in each country are always changing. It should be noted that we are not saying that everything is complex and too complicated to make policy decisions. In fact, we are saying the opposite. Overall policy must be country specific. The transfer of policy prescriptions/models from outside, especially outside the region, should be viewed with caution and skepticism.

At a pragmatic level, if you were to ask us to identify the priority agronomy/agricultural mechanization policy issues now in Bangladesh and Nepal, we would say they are technologies that address labor shortages, especially seasonal demands and large labor spikes, and technologies that reduce drudgery. Examples: (1) rice-harvesting machinery such as 2WT, 4WT and self-propelled reapers; (2) threshers and mini–combine harvesters; (3) alternative rice crop establishment technologies, and (4) direct seeding technologies such as seed drills, specifically reduced-till, non-puddled, and zero-till conservation agriculture seeders and planters . To these would need to be added concerns with water and energy management.

Topic 2: Leveling the Playing Field in Rural Mechanization

The second area concerns the leveling of the playing field for the creation and dissemination of information on smaller-scale rural mechanization processes. We have shown that during the past 50 years in parts of South Asia, smaller-scale equipment has been spreading rapidly and increasing the intensity of the use of agricultural and other rural resources. Symptoms of increased intensity are increased cropping intensities and yields; careful use and management of soils, fertilizers, and water; and local processing of products. However, the data that are being promoted on growth still do not include this evidence about the role of smaller-scale equipment. Therefore, there is a need to integrate information and evidence about smaller-scale mechanization into policy debates. While situations will vary, some measures that might be considered are the following:

1. **Research and policies that promote and regulate local and international markets.** The case of Bangladesh shows that since the late 1980s there has been a pro-market trade policy for the import of capital/intermediate goods such as inexpensive, lightweight, multipurpose, and good enough Chinese diesel engines. India appears now to be adopting that strategy, as the sales of Indian smaller-scale equipment powered by Chinese engines is expanding rapidly.

2. **National and international R&D organizations.** We referred earlier to the closing down of agricultural and rural engineering institutions in the Food and Agriculture Organization of the United Nations, CGIAR, and other organizations.[37] Now is the time to reconsider the rationale for those decisions, especially in light of current global policies to promote value-added chains. The development of suitable smaller-scale technology can be justified not only on equity grounds for the distribution of value added in the chains but also on efficiency in overall economic growth.
3. **National technology use surveys and policy analysis.** One of the reasons this paper remains illustrative is that it is hard to find data sets that can provide the information necessary for conducting an overall policy analysis on rural mechanization issues. Different agencies collect and keep data for different purposes. The numerous problems with definitions have been covered elsewhere.[38] In addition, mechanization is a fast-changing area; data might need to be collected quickly in a cost-effective way. Census data and regular national samples surveys frequently do not contain the details needed for this area of policymaking, and thus cost-effective supplementary surveys are often needed. We suggest that attempts such as the International Development Enterprises data we presented here would be a useful start as regards national figures. The data can always be enhanced once the process of this type of analysis is established. A second dimension of data collection and analysis is the importance of cost-effective field surveys to identify what is actually happening in the field.[39] As we have discussed at length, there is almost a free for all now in international arenas of rural mechanization, where lobby groups, specialist academics, and epistemic communities all promote their own knowledge and products.
4. **Selective time- and location-specific equipment R&D.** In spite of the mixed history of applied problem-focused public-sector R&D, it still has a significant role to play, especially in agricultural/rural mechanization. Given the successes and failures of the past, perhaps we need to be more skeptical of the content of R&D proposals as they are produced for many purposes and audiences. In keeping with our suggestion of avoiding generalities, we recommend that the ongoing technical research in Bangladesh examine the efficiency of axil flow pumps, the impact on wage labor of combine harvesters, and the yield and economics of replacing manually transplanted rice with mechanical transplanting or nonpuddled direct seeded rice. All these are examples of the type of applied rural engineering research that needs funding.
5. **Action research to investigate alternative techniques and institutional models.** There is a role for action research as long as it is recognized from the start that the very experiment represents a position along a policy choice agenda. For example, in Nepal there is an action research agricultural mechanization project supported by a major Nepalese airline, Buddha Air. This research is looking at the viability of joint management where larger and smaller tractors and other equipment are shared. Part of the rationale of the project is that to gain economies of scale from equipment, there needs to be a joint management of the equipment. Another action research project might just as easily look at providing credit to small and/or tenant farmers to buy 2WTs and sell custom services. The 2WTs can then be hired out to neighboring farmers for tillage,

[37] For more details see Biggs et al. (2011).

[38] See Biggs, Justice, and Lewis (2011); Justice and Biggs (2013); and Steele (2011).

[39] We are concerned here not with conventional long-term data collection surveys or with monitoring and evaluation activities of a project for which there is a large literature on practice. We are proposing special purpose surveys to actively seek out specific information about a specific topic. Bangladesh has a long history of such quick, rapid, informal, reconnoiter, innovator surveys going back to the mid 1970s. For an example, see Yunus and Latifee (1975). At the time, other groups in other parts of the country were carrying out similar surveys under the umbrella of the Ministry of Rural Development.

threshing, transport, and a whole range of other activities.[40] The second part of action research, which is always problematic, is translating the information gained into information that is relevant, useful, and effective in the broader economic and policy sense[41].

6. **Information, credit, and fair markets for poorer rural entrepreneurs.** Two-wheeled tractors have shown themselves to be a profitable investment in Nepal and Bangladesh for many years. It is rare that the total payback period was more than two years.[42] Credit normally comes from personal or family sources. While poorer people need access to formal credit, there has been no provision in the formal banking system in Nepal to provide credit to buy such equipment, unless the client has land or other assets to mortgage. It is a situation where a special provision is needed in the formal banking system to make loans available to the smaller entrepreneurs for the purchase of smaller-scale equipment. Gaining access to reliable and relevant information is also an issue. Although the Internet provides a profusion of alternative choices, accessing and validating the information and then obtaining the equipment is often a formidable task for a poor rural woman with a small amount of potentially irrigable land in the western mountains of Nepal and whose husband and son are away in the Middle East or East Asia. It is also a major challenge for government or donor agencies to try to address these issues in a cost-effective way.
7. **Field-based research to test claims of efficiency and productivity of the different scales of technology.** One of the ways to further open up the policy debates in this area would be to encourage and fund field-based research on different scales of technology. This would need to include research that also looks at the actual practice in the economy, such as the historical studies reviewed here.

Topic 3: Methods and Rewards for Collecting Information from Informal R&D

A policy lesson to come out of the spread of smaller-scale equipment is the importance of obtaining information about what is happening in the field and acting on the information in a timely manner. This is particularly important for rural engineering techniques and institutions as many useful techniques and institutions arise out of informal R&D in the practices of the rural economy.[43]

An example of informal R&D is the flexible and inexpensive lay-flat hose pipe used for irrigation. It was rural artisans and farmers who “looked over the fence” and saw something that was potentially useful and created what we would argue is one of the most important new irrigation technologies in recent years. Although the lay-flat pipe is common in some areas, it is unknown in areas where it might be useful, efficient, and pro-poor. The recent spread of ice pop wrappers being used for cheap drip irrigation in North India is another example of informal R&D (Pearce 2012). The bamboo tubewell and water/energy markets in Bihar and Bangladesh water markets, both from the 1970s, are another two examples of how institutional innovation has taken place in the field. Sometimes the start was stimulated by formal interventions of the government, donors, and NGOs, and on other occasions it would be hard to say what the start was. In any event, the policy lesson is the importance of conducting rapid and cost-effective surveys to keep abreast of, and assess the outcomes of, informal R&D and what measures can be taken to capitalize on informal R&D innovation. Bangladesh has a long history of developing cost-effective methods for this sort of monitoring. For example, see the surveys by many organizations under the Ministry of Rural Development (Biggs 1978; Yunus and Latifee 1975). Cost-

[40] For an example of this type of credit program, see the BRAC/Central Bank of Bangladesh Tenant Farmers Development Project (BRAC 2012).

[41] Sometimes called the “scaling up and scaling out” of research results.

[42] Other papers in the 2013 Bangladesh workshop on rural mechanization confirm this. See, for example, Hossain et al. (2013) and Ahmed (2013).

[43] We do not assume there will not also be informal research and development creating “undesirable” innovations.

effective, informal R&D surveys by engineers and social scientists could provide key information for facilitating the spread of the new technology. We posit that these innovations are being used for a whole range of activities for which they may not have been formally tested and that a whole range of novel institutional models are evolving for their sourcing, financing, maintenance, and use.

Other informal R&D is being conducted by small-scale entrepreneurs from Nepal who are touring China agromachinery markets and fairs for ideas and equipment. From this informal market exploration and finding small-horsepower mini-tillers five or six years ago, the mini-tillers are now spreading rapidly in the rural Terai and mountains. More recently, small businessmen have brought back from China half-horsepower mini maize shellers and manual maize jab planters to test in the market in Nepal.

Some of these informal R&D surveys might be directed at the more formal activities of government, donor, and NGO programs. Frequently, the monitoring and evaluation activities of these planned projects become preoccupied with monitoring the planned activities and outcomes of the project to ensure they are in accordance with the original plan. They are frequently less interested in the unintended but positive outcomes. Paradoxically, in this regard, some donors in Nepal encourage promarket solutions for developing irrigation but then conduct few cost-effective surveys of actual irrigation practices in the markets. Funding of smaller-scale projects with different types of equipment and institutional models should be encouraged; however, care needs to be taken to avoid privileging this type of action research as a primary source of innovation.

We see it as important that engineers use rapid assessment techniques for the collection of survey data. This type of research method is often lacking in engineering curricula. This creates a problem for policy discourse, as this type of field information is then either collected in a selective and ad hoc way or presented by social scientists. Both methods lead to difficulties for integrating the survey information into engineering policy discussions. We advocate strengthening of field survey training and practice in engineering schools.

Engineering equipment and institutions are proliferating in rural areas, such as mobile phones, solar panels and pumps, locally made or imported diesel-powered three wheelers, rain and water harvesting methods, and micro hydro. What we are calling for here is cost-effective and proactive surveys designed to capture data on these activities as they are unfolding in the field. The formal monitoring and evaluation mechanisms of data collection for projects and programs often are not designed to collect and act on this type of information in a timely way.

Topic 4: Growth of Rural Industries and Sector Linkages

Keynesian economic frameworks such as national (Leontief) input/output analysis help focus attention on the importance of (1) backward and forward linkages between different sectors in an economy, (2) the analysis of how the output of the national economy is consumed locally/exported, and (3) the country's relationship to international trade. The 2WTs and smaller-scale pump sets are intermediate (capital) goods, that is, they are not consumed themselves but are crucial for the production of other goods and services.

In the cases we have reviewed above, the spread of a specific type of good enough and cheap enough intermediate good has been central to the intensification of agriculture and the rural economy. These are the single-cylinder diesel engines to power irrigation pumps, boats, tractors, tempos, generators, mills, and rickshaws. In Bangladesh and Sri Lanka, this mainly has been Chinese equipment. In Thailand, the dominant source has been local manufacture under license of Japanese and Korean engines. The strong backward linkage from imports or local manufacturing sectors to the agricultural sector has been critical to the intensification of agricultural production. As we have shown, the smaller-scale engines are also important in many other sectors, for example, road and river transport, processing, electric power generating, and harvest and postharvest operations.44 As intermediate goods, these engines have made

[44] Much of the time, these engines have not been used for a specialized sector purpose, but the same engine is used for multiple services.

contributions to many economic sectors. Local manufacturing and repair facilities also have been established that have provided local rural productive employment and strengthened a local, adaptable industrial capability. The growth of this import/engineering industry has been important to agricultural and rural economics in the South Asian countries we have examined[45.] Therefore, the lesson for agricultural growth policy is that the strengthening of relevant engineering capacities in backward- and forward-linked sectors is as important as any direct attention to the agricultural sector itself. Smaller-scale equipment in both the agricultural sector and the linked sectors results in a robustness, flexibility, and sustainability in the local rural economy that might otherwise be absent when larger-scale equipment dominates the rural landscape.[46]

The growth of the poultry industries in Bangladesh and Nepal is another example of the importance of strong sector linkages. In Bangladesh, it is not uncommon to find maize yields of 6 tons per hectare on small-scale holdings where 2WTs are hired in for tillage operations, careful fertilizer application by hand, followed by multiple irrigations from hand-bored shallow tubewell and water lifted by 5-horsepower diesel pump sets. In Nepal, another example of a strong backward linkage development is the use by farmers, and other rural entrepreneurs, of inexpensive plastic lay-flat irrigation hose pipe for irrigation purposes. This led to the establishment of several Nepali plastic manufacturing companies (de Bont 2014).

In light of the above evidence, our policy recommendations on linkages are the following:

1. To strengthen intersectoral linkages, albeit a difficult task as sectors are generally defined by government, donor, and NGO bureaucracies
2. To support small-scale rural manufacturing and repair industries
3. To support vocational education and training
4. To introduce and strengthen courses on smaller-scale rural engineering concerns and field survey methods in engineering schools

Topic 5: Energy and Water Prices and Machinery Equipment Subsidies

Overall, government energy policy (provision and pricing of alternative energy sources) is central to influencing future patterns of rural mechanization and hence strategies for agricultural and other forms of rural development.

National policies need to take into account positive and negative externalities of national resources/common property use, such as the sustainable management of groundwater sources, arsenic problems, drainage, and flood control. These are conventional areas of public policy analysis[47]. We have noted how Keynesian input/output Leontief models can be used to analyze the energy and water management dimensions of national economic growth.

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[45] Bangladesh studies that looks at the nature of backward and forward industrial linkages in the context of agricultural and rural machinery see Mandal, 2002 and2013; Alam et al, 2004.

[46] There is a well-established literature on growth linkages, which we will not review here except to say that backward and forward linkages are not automatically strong and have not necessarily led to strong employment in the agricultural sector and in linked sectors. Whether linkages are strong or weak depends also on trade opportunities, patterns of land ownership, and other agrarian structures. For a review of these issues, see Hart (1993). We argue here that smaller-scale mechanization has led to strong rural linkages and rural development. The importance for our understanding of rural change, and policy analysis of whether small- and medium-scale industries are treated as in the industrial or agricultural sectors, is a well-known problem in economics and was empirically illustrated by Falcon (1967). This issue has significance for our argument here because if smaller-scale rural entrepreneurs with smaller-scale engines and other equipment are treated as agricultural units, rather than as industrial or service units, then an observer will be missing many of the changes in economic growth, distribution of incomes, and economic capacity development taking place in rural areas. This is another illustration of how choices as regards data collection and presentation methods influence what is seen or not seen.

[47] It is beyond the scope of this paper to discuss the way energy prices directly influence patterns of rural mechanization and the efficiency of resource use in different countries and regions. The article by Shah (2007) well illustrates how cheap, subsidized diesel fuel leads to inefficient production practices and gives advantages to diesel engines over other sources of energy.

Topic 6: Path Dependence

The last topic we wish to address is how past policies affect the ability of policy actors to direct the economy in new directions. In economic analysis, this is seen as a path dependence problem in which the same technological trajectory is maintained when a national, economic analysis might suggest a different strategy.[48] One of the features that leads to path dependence is subsidies. For example, rural entrepreneurs and farmers delay the purchase of equipment because, even if a piece of equipment is profitable, it is pointless to buy it today if you can get to the head of the line and get it cheaper under a subsidy.[49] Recently, 2WT sales in Bangladesh declined as a result of the introduction of subsidies for them. Similarly, in the early 2000s farmers in Nepal nearly stopped purchasing diesel pump sets for irrigation for nearly two years because they were waiting for the return of subsidies that never came.

One of the ways of addressing this would be to conduct a policy analysis to assess the lobbying demands and needs of different groups for subsidies and other preferential treatment. The agriculture sector in most countries is generally protected and subsidized. In South Asia, different "Green Revolutions" were usually highly subsided with cheap energy such as urea and water. Not reducing subsidies when they can no longer be justified from a national policy perspective leads to path dependence. The analysis would also have to look at the dominance of different actors in professional positions in the academy, research institutions, and policy arenas and the way they promote path dependence.

[48] It has long been argued that the plant-breeding institutions of the CGIAR network are caught in a path-dependent technological trajectory in which plant breeding is seen as the priority technological way forward in addressing agricultural problems (Hogg 2000). This paper supports that view by arguing that, without the rural engineering inputs, subsidies, and guaranteed prices to agricultural crops in some cases, the high-yielding varieties would not have been able to express their potential. However, this did not lead to a concentration on water management, agronomy, and other rural engineering issues but rather a preoccupation with funding plant sciences at the cost of other technological priorities such as smaller-scale rural mechanization for agricultural intensification and rural development.

[49] Which farmers get to the front of the line for limited subsidies is yet another dimension for policy analysis. The effect of agricultural mechanization subsidies on the agricultural manufacturing sector is beyond the scope of this paper, but needs analysis.

6. CONCLUSIONS

In South Asian countries, the spread of smaller-scale equipment, especially that powered by diesel engines up to 20 horsepower, has been accompanied by the intensification of agriculture and other rural economic activities. The spread of small-scale equipment has resulted in widespread mechanization of the agricultural sector. It also has been accompanied, in most cases, by some workers leaving rural areas and finding employment in urban areas and in the overseas remittance economy. In many areas shortages of labor at peak times have led to substantial increases in real rural wages.

In regions where smaller-scale mechanization has taken place, there has also been a growth of rural industries and strong linkages with the broader national economy. Whether by design or not, it appears that markedly different patterns of smaller-scale rural mechanization over time have led not only to agricultural production increases but also to broad-based rural and economic development. As these patterns of smaller-scale rural mechanization have taken place in today's global economy, they cannot be portrayed by the proponents of larger-scale commercial agriculture as an outdated romanticization of smallholder agriculture.

It is our hope that there will be increasing interest in the "silent and hidden" revolutions of the spread of smaller-scale equipment and that broad-based rural development, such as worthwhile rural employment and careful and intensive use of water and energy sources, will again become important goals of economic development. There is now empirical evidence on a grand scale that shows it can be done.

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