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Rural mechanization for equitable development: Disarray, disjuncture, and disruption

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Summary

Motivation: Agricultural mechanization was once a mainstream issue. From the 1990s onwards it received less priority, as public policy concern for equitable economic development in rural areas faded. Despite recent signs of renewed interest, questions of rural mechanization require more systematic attention. After a long period of neglect, our knowledge is in disarray.

Purpose: This article traces the evolution of thinking about rural mechanization. It examines how three increasingly important factors affect or potentially affect mechanization: (1) expansion of capital goods markets; (2) evolving urban–rural linkages; and (3) climate crisis.

Methods and approach: The article reviews the literature that documents long-standing debates, and that which records changes in the rural areas of the global south in the 2010s.

Findings: Public policy for rural mechanization was often seen in the 1960s as central to rural development. When neoliberal economics rose in the 1980s, it was thought issues of mechanization could be left to the suppliers and customers in the market. In the meantime, and especially in Asia, many rural operations have been mechanized, but these changes have attracted relatively little attention from either researchers or policy-makers.

In the 2010s, the pattern of mechanization has been influenced by changes in the production of machinery and the way that suppliers try to sway policy-makers towards favouring their products; by changes in the relations between urban and rural areas, including the emergence of rural labour shortage and the availability of remittances for capital investment; and by the challenges posed to farmers by global heating and the climate crisis.

Each of these trends is potentially disruptive, risking disjuncture between our understandings of the changing realities of "real world" rural livelihoods and wider political economy on the one hand, and the need to ensure the relevance of research agendas to policy priorities on the other.

Policy implications: Policy-makers need to embrace a more holistic view of mechanization based on evidence from multi-disciplinary research. Policy needs rebalancing to enable a more integrated view of national economies; a greater recognition of the realities of

mechanization for smaller farmers and small to medium entrepreneurs; and improved data collection, including experimenting with public–private partnerships for data collection.

KEYWORDS

agricultural mechanization, capital goods, rural development, rural industrialization, rural livelihoods, rural mechanization, urban–rural links

1 | INTRODUCTION

After a long period of neglect, agricultural mechanization is back on the agenda. Since 2015 there has been a flurry of new interest in the subject. For example, there are calls for "sustainable agricultural mechanization" in order to respond to rising demand for food created by increasing urbanization and population growth (FAO & AUC, 2018), intensifying agricultural production and building "green value chains" (Sims et al., 2016), and addressing gender inequalities through promoting labour-saving technology and more inclusive small businesses (van Eerewijk & Danielsen, 2015). The International Food Policy Research Institute (IFPRI) has recently looked back to consider whether Asia's history of "success" in adopting rural mechanization could provide useful lessons for African countries engaged in strengthening their farming systems and promoting strategies for rural transformation (Diao, Silver, & Takeshima, 2016; Diao, Takeshima, & Zhang, 2020). Issues of food security and emerging markets have prompted a revisiting of key earlier debates around mechanization, particularly those during the 1970s and 1980s (Daum & Birner, 2020). A recent IFPRI meeting examined the importance of new forms of partnership with the private sector that moves beyond top-down state-led technology interventions of the past (Richter, 2019).

But how well do today's researchers and policy-makers know these earlier debates? And how far do their themes remain relevant under today's changing conditions? IFPRI's study acknowledges an enormous diversity of experience, but notes that our knowledge base remains fragmented, and that "the literature has not coherently documented how and when mechanization grew and what impacts it had" (Diao et al., 2020, p. xxix).

This article takes a historical approach to selectively review issues of agricultural mechanization and rural industrialization. We define agricultural mechanization as the shift from human labour to other sources of energy in the agricultural value chain, along with the production and utilization of equipment that can enable this shift. Rural industrialization refers to value-added commodity production that utilizes productivity-increasing technologies, enabling rural workers to retain surpluses that would otherwise flow to urban areas (Mutersbaugh, 1997). Its forms vary across different contexts, but include agricultural technology manufacturing and repair workshops, processing and packaging industries, and aspects of the so-called rural non-farm economy (RNFE) such as transport, construction, and furniture making.

In making the case for renewed research and policy interest, we argue that mechanization was once a mainstream theme for those seeking to promote equitable rural development. During the 1970s and 1980s an emphasis on state-led mechanization efforts led to wide-ranging debates about how governments could best make cost-effective investment decisions in agriculture, choose the "right" agricultural technologies to optimize productivity and employment, and balance trade-offs between the interests and livelihoods of large farmers, small farmers, and landless or land-poor farm workers. For example, there is evidence that smaller-scale mechanization provides more jobs, contradicting conventional mainstream assumptions that capital (machines) substitutes for labour. Machines may substitute for energy from animal draught power, reduce human drudgery, and enhance the timeliness of operations (Biggs & Justice, 2015).

During the 1990s the picture changed. There was a retreat from state planning, and the rise of neoliberal policy agendas contributed to a view that technology choice for agricultural mechanization was best left to markets,

effectively closing down these earlier debates. In this new policy environment, diverse research interest groups within the international agricultural research system were now expected to compete among themselves for scarce research funds. Those specialists working on agricultural mechanization and engineering were generally unable to gain much influence in the mid-to-upper levels of the system, and therefore lacked the champions needed to make their case. Nor were they particularly effective at communicating their past achievements and successes. On the contrary, they were tainted by their association with the imagery of earlier high profile "green revolution" failures, such as abandoned tractors and rusting pumps, and they were rarely included in the new "farming systems" groups that were emerging.

The subject of rural mechanization also fell foul of a new generation of critical rural development practitioners and activists, many of whom saw labour-saving technologies as primarily serving the interests of agribusiness, bringing negative implications for poverty and inequality, and incompatible with "appropriate technology" ideas that were in vogue. The result was that funding ran dry, policy-makers, development researchers and activists lost interest in the debates around mechanization, and knowledge and data on the subject declined. While there was also a continuing tradition of critical political economy research on agrarian change issues, these sometimes lacked fine grain detail. A dominant focus on the "generalized narratives of agrarian crisis" (Sinha, 2020, p. 1539) brought about by neoliberalism and corporate strategy meant that a sense of farmer agency was lost, risking "treating the peasantry as a passive victim" (p. 1536).

Building on an earlier research note on this theme (Biggs et al., 2011) we argue that agricultural mechanization and rural industrialization should once again be regarded as important topics for equitable rural development. Despite the recent crop of new studies and reports, our knowledge remains in disarray. This disarray arises partly because of neglect, but also because much of our knowledge continues to be siloed. The dominant research perspective is one that draws heavily upon agricultural economics, but this needs to be combined with insights from engineering, political economy, and anthropology.

Moving forward, we suggest that mechanization is best considered in broad terms, going beyond a narrow focus on farming, or an emphasis on larger-scale equipment. We need to move past big machine bias, and we need to look at how these technologies may have wider implications. For example, ethnographic work undertaken by anthropologists favours a more holistic approach, as in the case of Lambertz's (2021) research on the use of small engines for river boat transport. Much of the literature has also focused on four-wheel tractors or harvesters when we know that smaller, less visible types of mechanization such as power tillers have long been important in countries such as Bangladesh and Vietnam. David Biggs (2012) writes about the importance of small machines as "everyday technologies" that lacked the visible symbolic power needed to demonstrate the moment of "take off" that was demanded by Rostow's influential (1960) modernization theory narrative. For these reasons, we favour taking a "rural" rather than an "agricultural" mechanization approach. If agricultural mechanization is defined too narrowly, aspects of the RNFE such as transportation, engineering, and infrastructure are all too easily overlooked.

We also need to guard against overgeneralized and decontextualized thinking that risks overlooking, for example, the diversity of local soil and water conditions, or differences in local household livelihoods opportunities and strategies. A more unified perspective is now needed in which the local, ground-level realities faced by rural producers in different settings are analysed in more holistic ways against broader changes in the wider system of national and international political economy. This context includes a vast (and changing) global manufacturing system for "capital goods," by which we mean assets used in the production process, in this case agricultural and other machinery and equipment such as two- and four-wheel tractors, irrigation pumps, and threshers.

Re-engaging with these questions matters for today's challenges in relation to rural household livelihoods, equality between rural and urban areas, and building sustainable environmental policies and practices in the face of climate change pressures. To do this we need to reconnect with some old issues (such as building interdependence between sectors, and support to small farms and rural enterprises) and confront some new ones (such as the value of new forms of partnership, and responding to the challenges of climate change).

The article proceeds as follows.[1] We begin by selectively surveying the history of debates around mechanization since the 1960s by distinguishing four main periods, the main features of which are briefly summarized. We then identify three aspects of contemporary disruptive change that help demonstrate the renewed relevance of debates around agricultural mechanization and rural industrialization. First, we describe how capital goods markets have expanded and taken new shapes, driven both by international finance and aid agencies. Second, we show how changing urban–rural linkages have important implications for production, viability of rural livelihoods, and social stability. Third, we examine how climate change pressures raise new questions about the relationship between production, technology, and the food/water/energy nexus.

Each of these trends contributes to change in rural areas that is potentially disruptive, helping to produce a disjuncture between research agendas, rural development policies, and "real world" rural livelihoods. To address this, we suggest the need for a new multi-disciplinary research agenda that requires us to combine insights from such fields as agricultural economics, engineering, and anthropology. Research will need to pay close attention to both history and diversity of experience. It also implies a move beyond purely technical, efficiency-led discussions to engage with the everyday realities of rural livelihoods as experienced by rural people, the wider political economy, and a more pragmatic future-oriented view of rural transformation that questions past assumptions. This will provide a sounder basis for building new priorities for policy.

2 | AGRICULTURAL MECHANIZATION IN HISTORICAL PERSPECTIVE

In this section we briefly summarize the key discussions and priorities since the late 1960s. In Table 1, we outline five broad phases of international debate, illustrated with selected examples from the mainstream literature. More detailed timelines of international debates concerning agriculture and rural development can be found elsewhere, such as in Ellis and Biggs (2001), and for the RNFE, in Haggblade et al. (2007). We focus our attention primarily on international debates about agricultural and rural mechanization. By "mainstream" literature we mean studies and reports from institutions such as the World Bank and other development donors, as well as organizations that form part of the CGIAR research partnership (CGIAR, n.d.). We do not aim to offer a comprehensive review, but provide selective examples to illustrate our arguments.

2.1 | Phase 1: 1960s—Modernization, technology transfer, and economics

During the era of modernization theory, there was considerable interest in mechanization. Development economics was dominant and there was a modernist faith in the idea of "technology transfer." Governments and donors had a high degree of confidence in the role of national economic planning within mixed economies.

Within a Keynesian economic approach, Leontief's "input–output" model made it possible for planners to quantify the interdependencies between different sectors of an economy at the national level. It highlighted the importance of backward and forward linkages between different sectors in an economy, enabled analysis of how the output of the national economy is consumed locally/exported, and showed the country's relationship to international trade. Built into national accounting in many countries, it provided a useful tool for studying regional economies within nations, and was also widely used in policy analysis to set out the possible outcomes of different technology choices in different sectors. Falcon (1967) applied the model to rural mechanization in Pakistan, where he demonstrated the importance of treating small and medium-sized rural enterprises as part of the industrial

[1]The article takes a selective approach to the subject, highlighting three contemporary themes that we consider particularly important. We make no claim to be comprehensive, either in our review of the literature (we do not discuss engineering research in depth, or forestry/fisheries), or the geographies covered (Asia and Africa rather than Latin America or the former Soviet Union). It draws on each of the authors' own personal experiences with these issues, mainly in Asia, and particularly in relation to the CGIAR research system.

TABLE 1 Main phases in agricultural and rural mechanization debates

1960s	1970s	1980s	1990s	2000s	2010 and beyond
Phase 1: Early classic debates on rural development in national economic development. - modernization and technology transfer - input–output models					
	Phase 2: Open debates and field-based empirical research. - technology choice, class differentiation effects - farmer first, appropriate technology and participation				
			Phase 3: Closing down of debates, decline of field work, research and development (R&D) and data collection. - markets as arbiters of technology choice, small-scale credit - institutional economics and local institutions		
					Phase 4: Decline, disruption, and disjuncture - large farm enterprise investment - climate crisis

Source: the authors.

rather than the agricultural sector (as was common at the time) to gain a properly integrated view of changing economic growth, income distribution, and economic capacity development in rural areas. By considering the flows of goods and services between sectors, and the multiplier effects of changes to one or other sector, this made it possible to model changes and patterns in the level of final demand (consumption). The model emphasized the structural and institutional dimensions of economies, but its limitations included an assumption of constant prices, and the tendency to make investment behaviour exogenous to the model.

By the late 1960s the so-called "green revolution" in agriculture (the introduction and use of new high-yielding seeds and modern inputs) had begun to generate debates about the employment effects of agricultural mechanization, and about the relationship between farm size and productivity. Prefiguring work to come, research began to highlight the importance of small-scale rural capital goods industries that provided agricultural equipment and services, an aspect of the local economy often overlooked by planners. For example, Sansom's (1969) research in Vietnam highlighted the importance of local innovation in the spread of irrigation pump engines taking place "below the radar" of planners, to borrow Kaplinsky et al.'s apt title (2011). Instead, "informal" R&D by small-scale rural entrepreneurs and farmers was driving innovation, such as modification of small engines intended for single use for multiple purposes such as ploughing, pumping water, processing crops, and transportation (Biggs, 1980).

2.2 | Phase 2: 1970s to late 1980s—politics, poverty, and participation

Modernization theory was now being challenged by political economists who analysed agrarian economies in terms of unequal household access to land, labour, capital, and markets (e.g. Griffin, 1979). Understanding agrarian structure became seen as important to inform government choices around rural technologies, since mechanization risked exacerbating class-based differentiation among rural households. In some areas, the introduction of

new technologies favoured large farm households with substantial resource endowments and market access, with less positive effects on the livelihoods of poorer groups. In South India, for example, rural traders were able to invest profits in new tube wells. They established lucrative entrepreneurial businesses to sell water to local farmers, further increasing their wealth and power (Harriss, 1981).

These analyses also began to generate new programmes in international agricultural research centres that emphasized the specific challenges faced by smaller farmers. There were also new commitments during the early 1980s by governments, the World Bank, and other donors to forms of monitoring and evaluation that allowed them to learn from projects and programmes (Casley & Lurie, 1982).

Cornia et al. (1987) placed agricultural mechanization firmly within the national economic context and argued against it being understood only as a narrow sectoral issue. While national planning systems and input–output models continued to hold sway, there was now also an expansion of market-based approaches. There was a new focus on providing financial services and small enterprise support to farmers. One example of this was the "business investment analysis" for tractor farmers promoted by the Organisation for Economic Co-operation and Development (OECD) (Winkelmann, 1972). Yet government intervention continued, in terms of agricultural prices, with energy subsidies in particular underpinning the green revolutions in Asia.

An influential book by Pingali et al. (1987) on mechanization in Africa developed a model based on Hayami and Ruttan's concept of "induced innovation" (the idea that labour shortage created pressure for mechanization) and farming system intensification (Hayami & Ruttan, 1971). Focusing on demand-side factors, it suggested that mechanization policies tended to fail because farming systems had not intensified enough to generate farmer demand for mechanization to help overcome labour constraints and reduce drudgery. The result was that policy-makers in agencies like the World Bank became convinced that location specific mechanization was not a cost-effective option for much of Africa (Amanor & Iddrisu, 2021).

A key insight during this period was the need to pay more attention to regional and local difference. The agricultural sector was not uniform, with diverse conditions faced by different kinds of farmers, and rural institutions were characterized by interlocking factor and product markets (Bardhan & Rudra, 1978). This led to debates about whether, for example, bullocks or tractors were "better" technologies in terms of their production and employment implications for different farms sizes (e.g. Binswanger, 1978). The gendered dimensions of these decisions were also made visible. In Bangladesh, for example, there were concerns around the negative impacts on rural women's employment from the mechanization of small-scale rice milling (Ahmed, 1982).

"Rational" planning models were increasingly questioned by those who saw technology choice as often driven more by political interest groups, agribusiness, and outside donor agencies than national policy priorities or farm household interests. For example, one of us remembers the arrival during the 1980s of a fleet of 50 left-hand drive International Harvester Scout vehicles donated by USAID to Nepal's National Agricultural Research Centre (NARC). The influence of large commercial manufacturing companies was given more importance in debates around mechanization. For example, the OECD study by Yudelman et al. (1972) highlighted the influence of agricultural machinery lobby groups. The growing recognition of the political nature of agricultural policies was reflected in other mainstream thinking, such as the edited collection *Science, politics, and the agricultural revolution in Asia*, containing 15 papers from a 1980 symposium by the American Association for the Advancement of Science (Anderson et al., 1982).

The concept of "choice of technology" was rarely subjected to critical scrutiny, with only a few exceptions (e.g. Stewart, 1987). Furthermore, during the 1970s the choice that was available was usually a very limited one: between Western imported capital and energy-intensive machinery on the one hand, and an "appropriate technology" style of village-manufactured machine on the other. For many small farmers this was an inadequate choice if you wanted to mechanize your farm production. While there was growing availability of two-wheel tractors and pump-sets from Japan and South Korea, these were not generally affordable to small Asian and African farmers without subsidy. For example, the Japan International Cooperation Agency (JICA) provided long-term support to these kinds of technologies to farmers in Bhutan.

By the mid-1980s, the availability of cheaper Chinese-made "good enough" pump-sets, rotavators, and two-wheel tractors was improving the situation for farmers in Nepal and Bangladesh, who began to access the new opportunities these technologies provided, in some cases offering them the possibility of technology choice for the first time.

Private companies were found to be promoting their equipment in the Global South even where it was not appropriate to national development goals, including by lobbying rich country governments for inclusion of their products in their aid programmes. There were "cautionary tales" about the consequences of national policy-makers and aid donors who made the "wrong" rural mechanization choices that contributed to rural inequality (Timmer et al., 1975). For example, Burch (1979) documented the promotion of inappropriate four-wheel tractors in Sri Lanka during the 1970s.

Finally, there were new types of field studies and an increased availability of empirical data. The CGIAR centres developed well-resourced on-farm and on-station social science research facilities alongside their agricultural engineering divisions. Such work began to show the value of multi-disciplinarity and also fed into the new "participatory research and development" approaches that were gaining popularity. For example, Rhoades and Booth's (1982) work on potato storage was an influential study by an anthropologist and an engineer that illustrated the potential of working across disciplinary "silos." Energy and agribusiness also began to receive more attention in relation to mechanization. Chancellor (1978) undertook applied agricultural engineering research that examined the role of fuel and electricity flows in agricultural production. However, this was the type of committed field-oriented applied engineering work that was not to last.

The rise of participatory theory and practice fed into a new "farmer first" movement, which stressed the importance of "informal R&D" and indigenous technical knowledge, in contrast to formal research and innovation by corporations and laboratory-based scientists. This built both on actor-oriented sociology and earlier studies such as Appu's (1974) and Clay's (1980) work on the spread of bamboo tube wells in India and the use of small engines mounted on bullock carts to sell pumping services. Small-scale innovation was shown to be capable of producing local engineering solutions that led, for example, to new local custom service markets. Private sector innovation was taking place particularly in East Asia at this time (James, 2016). Alongside examples of private enterprise, non-governmental organizations (NGOs) such as the Intermediate Technology Development Group (ITDG) also began focusing on rural capital goods, rural industries, and agricultural services. Modernization theory had been ethnocentric in privileging Western technologies over local farming systems. Yet the "appropriate technology" movement offered a critique that also arguably helped move rural policy debates away from mechanization, since its proponents often insisted that machinery should be made locally—in places where this was often difficult or impossible.[2]

2.3 | Phase 3: Early 1990s to late 2000s—liberalization, markets, and commercialization

Everything changed in the 1990s, with less range and depth to rural mechanization debates. Binswanger's (1986) influential comparative historical overview of the patterns of agricultural mechanization had to a large extent marked the end of a long period of debate and discussion around this theme.

There were several explanatory factors at play. Neoliberal development agendas gained a stronger hold on policy-makers and economists, shifting attention away from public sector planning to market-based approaches to rural development. In the liberalizing rural economy, technology choice was no longer an issue for research and debate, but one that could simply be left to the market. The CGIAR system lost access to high levels of public funding and became more dependent on private sources, from philanthropic entities and agribusiness. Interest groups centred on the use of global plant genetic resources in plant-breeding programmes have generally been more adept at commanding limited resources that were available, sometimes through the use of alarmist narratives. Agencies such as the Food and Agriculture Organization of the United Nations (FAO) cut back their applied

[2]At the same time, NGOs such as ITDG and Appropriate Technology International helped to keep issues of rural industrialization and small-scale engineering equipment on the agenda during the 1980s and 1990s.

research into rural mechanization, and fewer field studies were commissioned. The International Rice Research Institute (IRRI) closed its agricultural engineering division.[3]

The new importance given to rural and agricultural markets might have been expected to move forward work on rural mechanization, but was highly selective in its research coverage. The ascendency of neoclassical economics in universities reduced the extent and influence of critical political economy approaches, and this impacted on rural development research in general. Also, more attention was now beginning to be focused on long-neglected urban issues. A continuing decline in the level of collection of national and regional data made it harder to capture the extent of a massive spread taking place of diverse rural capital goods, or the complexity of evolving small-scale market services institutions. There was continuing interest in the NGO sector, and in multi-sectoral partnerships for the delivery of agricultural services.

The rise of "new institutional economics" offered a fresh approach to understanding rural institutions in terms of asymmetrical information, sharecropping, credit, and labour markets (e.g. Hoff et al., 1993). However, less attention was paid to the new local capital goods markets and services that underpinned much of the "green revolution" in Asia. An exception was Hayami and Otsuka's (1993, p. 294) work on the Philippines which noted a shift from traditional land preparation by owner-cultivators or tenants using animals such that "ploughing has increasingly been contracted out to custom services that use small tractors in Central Luzon." While there was also some work on ground water and transport service markets, other important rural markets, such as those for engine services, were largely neglected. FAO's efforts to maintain a policy interest in rural mechanization were undermined by a backdrop of declining budgets for mechanization R&D, data collection and analysis (Kienzle et al., 2013).

Overall, the 2000s saw the continuation of mainstream neoliberal agricultural policy agendas. For example, the *World Development Report 2008* (World Bank, 2008) continued to present an orthodox prescription for market-based rural development based on investment in commercial agriculture. Little attention was given to agrarian structure issues, or to questions of mechanization and technology choice. It made a strong case for support for "small farmers" in broad global terms, but the report said little about the effective policy changes that would be necessary to ensure the playing field was made more even for poorer rural households. Instead, while the report usefully argued for agriculture to receive more international policy attention, the call was mainly for more investment in commercial agriculture and plant breeding.

2.4 | Phase 4: Late 2000s to the present—disjuncture and disruption

The financial crisis of 2008 once again saw policy-makers focus on issues of food security and stability, and this began a gradual revival of interest in agricultural technology and non-farm economy issues, including mechanization. Government and aid agencies in South Asia, for example, started talking about the importance of "scale appropriate technologies" (Biggs & Justice, 2020). At the same time, forms of disruption were occurring that now require new thinking about equitable rural development and mechanization.

Migration has contributed to a declining agricultural labour force, which in countries such as Thailand, has created local demand for mechanization in rice production (Cramb & Thepent, 2020). While some translocal families may find ways to maintain the coherence of their household across distant geographies, others may face disruption from the intensification of migration as communities, as certain groups such as the elderly, the poor, or those less educated, are left behind (Kay, 2008). Migration has, for example, changed the land use dynamics in Nepal's hills, with much terraced land lying fallow partly as a result of labour shortages (Devkota et al., 2020). In other areas of Nepal, however, migration income may be invested in small engines and other equipment. New

[3]The International Water Management Institute was a notable exception, since engineering technology has always been central to water management.

technologies, such as smartphones, offer opportunities for new internet-based rural businesses, including custom ploughing services.

Farm-size efficiency debates are increasingly questioned by findings that challenge the idea that larger holdings have economies of scale and are therefore naturally more efficient than smaller ones (Fuglie et al., 2019). For example, Zhang et al. (2015) show that, when smaller farms are able to hire in services, these types of scale economy decline. Additionally, Rigg et al. (2016), and Mandal et al. (2017) draw attention to the importance of small-farm income as a form of safety net within households diversifying their livelihoods. Small farms also enable some rice-farming households to complete basic tasks easily and quickly (such as hand broadcasting rice seed and renting in mechanized services for tillage and levelling), leaving household members free to hold down full-time jobs in other sectors. The issue of small-scale mechanization—whether in the form of buying in services or investing in small engines—has generally not been explored as much as large-scale mechanization (Biggs & Justice, 2015) and is even more pressing in the light of these new realities. Nor has the growth of capital goods industries in national contexts, mentioned for example in Cramb and Thepent's (2020) account of mechanization in Thailand, been given sufficient attention.

Mechanization issues are today reappearing on the research and policy agenda in both familiar and unexpected ways due to a range of factors we will discuss here: the expansion of capital goods markets, changing urban–rural relationships, and new rural challenges linked to the climate crisis and soil health.[4] These changes are producing a mismatch, or "disjuncture" (Lewis & Mosse, 2006), between the state of knowledge around patterns of technological change in rural areas (given the relatively low level of attention the subject has received until comparatively recently), the opportunities and challenges faced by people in rural areas as these new realities unfold, and the options open to policy-makers. This mismatch is partly apparent from research studies, but also perhaps emerges even more clearly from "grey" literature and newspaper reports that, while often anecdotal, provide up-to-date observations and insights that reflect realities on the ground and offer critiques of government policies (Gyawali et al., 2017). The result is that we will need to return to some old perspectives and debates, and also build new perspectives that can reflect and engage with the new realities.

The continuing contemporary relevance of technology choice and mechanization questions is suggested by, for example, a range of new types of project around gender and technology that are beginning to take shape. In Ghana, for example, The Women in the Driving Seat (WiDS) project of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) is being run in collaboration with the Ministry of Food and Agriculture (Cele, 2019). It seeks to improve women's skills and knowledge regarding the use of modern agricultural machinery, challenge the barriers and myths around women's relationships with agricultural machinery, and improve women's status and livelihoods.

At the same time, Western donors such as USAID and GIZ are once again linking aid and trade in their funding for agricultural mechanization. These donors increasingly promote their own multinational corporations' (MNCs) agricultural machinery-tractors made in the US or Germany, or in the case of emerging economies/donors, this may take the form of concessional loans provided by the governments of countries such as India and Brazil (Cabral et al., 2016). This trend may be weakening the traditional binary between North and South, which is also made more complex by the fact that Western-based multinational corporations increasingly manufacture capital goods in Asia and Latin America.

In the next section, we turn to three areas of disruptive contemporary change, each of which has implications for mechanization.

[4]Much of CGIAR's work since the early 2000s in agricultural mechanization is a result of concerns for soil health and promotion of conservation agriculture through various commercially available scale-appropriate machinery, e.g. no-till machinery seeders, planters that can manage and plant into surface mulch-residue, and harvester machinery that can leave an even mulch layer behind (USAID, 2019).

3 | CONTEMPORARY SITES OF RELEVANCE

3.1 | Capital goods markets

Globalization, technological innovation, and liberalization policies mean that rural capital goods markets have been expanding rapidly in recent decades, often driven by international capital flows and by aid agency policies. However, more research is needed on where the money is coming from that is used to buy smaller equipment. Rural capital goods—such as tractors, tube wells, agricultural processing, and storage equipment and machinery for transportation—remain central to agricultural production. We need to consider both the international political economy changes that drive these processes and the ground-level realities of local small-scale adoption and innovation. As Lambertz (2021, p. 1) describes in his study of Chinese diesel engines on Congo's inland waterways,

> globally circulating technologies…are able to unfold their economic, hydrodynamic and socio-technical affordances thanks to a number of local technical adaptations [by rural entrepreneurs].

Many rural areas have become populated with large-scale commercial production units with close links to urban and international capital. Alongside these, small-farm households with declining farm outputs co-exist, increasingly buoyed up by migrant remittances. Questions of small versus large farm efficiency have again become relevant. The justification for favouring large commercial farming is often one of economies of scale. Yet long-standing assumptions about large farms as more efficient are increasingly being challenged. Zhang et al. (2017) show that, as has often been suspected, smaller farmers can compete if they are able to hire in services. Rigg et al. (2016) take issue with the conventional economies of scale arguments, arguing that if there were such pervasive "natural" economies of scale in farming, smallholders would have declined long ago. They find that in East and Southeast Asia the traditional association of agricultural mechanization with large farms is no longer true and that "machines have become increasingly smallholder friendly" (Rigg et al., p. 126).

What are the mechanization options open to these households and can these be supported by policy-makers and NGOs?

Global agribusiness has expanded and changed its geographical focus. By 2012 the top three agricultural equipment manufacturers had equal or greater annual sales than the top three seed and chemical industries. The largest manufacturer in terms of revenue is US multinational John Deere, with revenue of USD 39.3 billion in 2019 (Macrotrends, n.d.), while China has long been the major source of cheap, "good enough" smaller engines and equipment for countries like Bangladesh and Nepal. As knowledge of this equipment spreads, diversity increases and quality improves, and China is fast becoming a major "supermarket" for rural capital goods for many countries, including India. India's Mahendra tractors division has over 40% of the Indian tractor market—the largest national market in the world—and has for the last decade been pursuing markets in the US and Canada. Its total revenue was reported at USD 6.8 billion in 2020 (Mahindra reports, 2020). While there are concerns voiced regularly around the lobbying influence of agricultural seed and chemical companies, less attention is paid to lobbying by agricultural machinery producer interests.

The trend towards international (and national) "land grabs" has implications for capital goods (Zoomers, 2010). International capital is investing in large tracts of land for large-scale export food production in countries of the Global South, encouraged by policy-makers eager for foreign exchange and trade opportunities. These large-scale agricultural enterprises in turn generally also require large-scale equipment and tractors, and are highly dependent on major investments in these capital goods. International agricultural engineering manufacturers and their suppliers have major interests in promoting "modern" equipment for these new forms of large-scale farming.[5] Research on these new forms of land acquisition has explored the role

[5]Similar to the US automobile industry's preference for promoting sales of F-150 pickup trucks and large SUVs, tractor-producing corporations have favoured selling fewer but much more expensive large horsepower tractors as these models provide the bulk of their companies' earnings.

of international capital, and its effects on small-farmer livelihoods, but has generally been less concerned with technology choice. One recent exception is Amanor and Iddrisu's (2021) study of the rise of tractor ploughing in Ghana associated with large commercial farm expansion, where the authors find a "scramble for land" and evidence of increased social differentiation.

Kaplinsky et al.'s (2010) work on innovation in emerging economies brought a fresh perspective on innovations in rural capital goods in the context of South–South trade and exchange. There has been increasing R&D in low-income countries since the 1970s, but this tended to not be focused specifically on the needs of poorer consumers. The phenomenon of "informal R&D" by farmers and local businesses sometimes led to useful adaptive gains through creative experimentation with technology, despite the limitations of more formal programmes (Biggs, 1980). The expansion of China and India as both producers of equipment and development partners may have disrupted established global corporate hierarchies of innovation, but the resultant "South–South cooperation" may also reproduce the long-standing tensions around "appropriateness" found in Phase 2.

While the rise of South–South co-operation is a positive trend, it can carry echoes of the now discredited "stages of growth" theories once favoured during the 1960s (Phase 1). It was common for technology-exporting countries to promote equipment that was unsuitable for use in the receiving country, and to organize farmer field visits from contexts so different that useful learning was unlikely. Today's Indian and Brazilian corporate commercial interests generate power imbalances that are masked by the deliberate use of "feel good" South–South narratives (Cabral et al., 2016), and may replicate the kinds of technology transfer problems (or disjunctures) reported by Burch (1979). The return of "aid and trade" links within Western aid, and the complex structures of MNC ownership, can mean that the South–South co-operation discourse may conceal more familiar "business as usual" relationships. For example, in one case tractors that were exported to Africa from Brazil with concessional loans and the claim that they are more suited to local conditions, turned out to be tractors made by New Holland—formerly a US company now owned by Fiat—and manufactured in Brazil.

Earlier "bottom up" observations of mechanization processes suggest that the spread of new equipment is often associated with informal R&D by small-scale farmers and entrepreneurs in the local rural economy. For example, the spread of cheap good enough "lay flat" irrigation pipes in parts of South Asia was arguably one of the most important rural capital goods ever for facilitating agricultural intensification. Few research articles or policy documents discuss where such innovation came from, or their significance.[6]

Similarly, the use of Chinese engines and associated equipment has been central to Bangladesh's increases in agricultural productively since the 1980s. The country has not followed the model of subsidized energy-driven large-scale mechanization, but instead relied on a period of initial basic low-level policy support for private sector spreading of small-scale "good enough" equipment and a policy of non-intervention thereafter (Mandal, 2017). Such low-level policy support was nevertheless a conscious policy rather than a case of laissez faire, and was aligned with support to engineering departments in the universities, strong links with the CGIAR system, and an engaged NGO sector that worked closely with government. Nor were these capital goods restricted to a single sector of the economy, but "jumped" from farm use for ploughing, irrigation, and crop processing to include wider uses for non-agricultural transportation by road and river. Similarly, local rental markets in capital goods emerged "below the radar" in many societies, underlining the crucial yet often overlooked importance of local innovation and other factors.

We need to know more, for example, about new technology-centred forms of rental markets in agricultural equipment that are emerging. For example, Anidi et al. (2020) have documented three information technology (IT) efforts to provide phone-based tractor (and other machinery) hailing platforms in Ghana, Nigeria, and Kenya, utilizing short message services (SMS) or smartphone applications. In contrast to the local informal

[6]Innovation is not linear, and may also be stimulated by wider geopolitical events, such as India's unofficial blockade of petroleum products and other commodities going to Nepal in 2015–2016, which contributed unexpectedly to the rapid spread of Chinese electric three-wheeler vehicles on the plains. Also important for the spread of two-wheel tractors in Nepal was the hands-on work by engineers with small farmers (Biggs & Justice, 2021).

enterprises previously observed in Asia (Lewis, 1996), these ventures are firmly located within the current ideological preference for private sector solutions to development problems. For example, there are reports of problems ensuring that drivers do not mislead farmers over the amount of land ploughed or the produce transported, which was not the case in the arrangements that emerged locally in earlier contexts of Nepal or Bangladesh. The private sector advisory group for Hello Tractor in Kenya includes private European companies such as Grimme, who make rotary tillers, and Lemken, who make mechanized planting equipment. However, turning a profit remains elusive for Hello Tractor, which continues to rely on donors (Daum et al., 2021). Finally, a growing number of studies such as Theis et al. (2019) document the gendered outcomes of the promotion of agricultural machinery.

3.2 | Changing rural–urban relationships

A second site of relevance is the changing rural–urban relationship in its multiple dimensions. As rural areas are more fully incorporated into global economic relations, rural people take advantage of new employment opportunities in peri-urban and urban areas, while urban and industrial economic relations are extended further into the countryside to draw on cheap rural labour. Urbanization has far-reaching effects on both agricultural production and the RNFE, disrupting traditional understandings of the rural/urban distinction and of the livelihoods and productive activities of people who live in rural areas.

Growing structural disparities between rural and urban areas may threaten both stability and growth. Rising rural wage rates and problems of increased labour scarcity for particular operations is creating new demand for the services of rural capital goods, such as agricultural equipment for irrigation or ploughing in parts of Asia (Wiggins & Keats, 2014). Small farmers are also increasingly exposed to higher levels of risk through their incorporation into international markets via crops such as cotton and soya, and rural reforms are badly needed to provide them with better access to inputs, mechanization, and local markets that do not remain interlocked and imperfect (Sharma, 2016).

While the growth of rural industries may be driven by technology repair workshops and crop storage processing, Haggblade et al. (2007) also identify the forces of "urban-led rural transformation" in India and China where there is rapid economic growth, improvement in rural infrastructure, and relatively high population density. One factor driving change in rural areas is the increasing cost of living and doing business in urban centres due to rising rents, growing congestion, and higher wages, leading to forms of "rural-to-urban commuting, temporary migration, and urban-to-rural subcontracting." As people move in both directions, rural areas are changing in diverse ways, but with new opportunities spread unequally between rural areas leading to disparities and the limiting of access in poorer settings, along with scattered and often fragmented institutional arrangements.

In the context of such changes, Oya and Pontara's work (2015) points to a lack of up-to-date analysis of rural wage market structures, or good data about how rents are distributed in value chains. In some areas we know that older modes of transaction, such as patron–client relationships and payments in kind are being replaced by newer arrangements based around financial market exchanges (Rodgers et al., 2016). However, access by poorer people to tractor, irrigation, and other services may continue to depend on the operation of informal structures and social institutions (Sugden, 2014). We know that the array of equipment available for rural mechanization has increased, yet there is little available evidence in relation to how new rural capital goods are being used. Nor is there sufficient recognition that the ownership of capital goods, or access to their services, could be becoming as important as ownership or access to land, or even more so. Rather than farm size being the crucial variable, it may be the size of a household's rural enterprise that matters. For example, Das Gupta (2019) documents the multifaceted portfolios of richer rural and urban households in three Indian states.

The growing numbers of rural migrant workers seeking overseas employment and increased national level remittance income will require policy-makers to revisit the role of rural capital goods in rural development.

While there is attention given to the way remittances may be used for education and consumption purposes, attention also needs to be given to remittances as an important source of finance for investment in rural economic activity.[7] Migrants' knowledge of a broader set of economic opportunities observed elsewhere may also be important for our understanding of rural change. New fine-grained fieldwork is needed if we are to understand the full diversity of context and experiences to contribute to policy debates. For example, Tania Li's (2014) anthropological research in Sulawesi, Indonesia, discusses the lack of productivity/wellbeing that exists in some rural "agricultural" communities, but that remains masked by the role played by remittances in supporting the local economy.

3.3 | Climate crisis pressures

Finally the climate crisis requires us to make connections between agricultural mechanization and rural industrialization, and the interlinked issues of food, water, and energy.

Though long-standing, connections between agricultural mechanization and energy are both underappreciated and complex, and go well beyond the dominant idea that mechanization simply substitutes capital for labour. Earlier planning models included energy supply as a key feature of mechanization policies during the 1960s and 1970s, when provision of useable energy to farmers was seen as key to promoting agricultural mechanization. India's "green revolution" relied on cheap energy, underwritten by policies that provided extensive subsidies to agricultural production, and to large farmers in particular. Cheap electricity and diesel were provided for pumping water, tilling fields, and threshing crops, along with other inputs such as urea. Subsidies were also given to public sector transport systems used to deliver fertilizer and market crops. Each of these policy choices has had economic, social, and environmental consequences that, because of the climate crisis, have now to be addressed.

Earlier narratives of mechanization are disrupted not only because we need to rethink the ways energy is produced and consumed, but also because agriculture itself has come to be viewed as a main contributor to climate crisis. Increased deforestation to make way for farms, the contribution of methane produced by livestock farming to greenhouse gases, and the wasteful use of scarce water resources all mean that the previous benign view that producing more food through agriculture is a worthy policy goal no longer holds.

Technology is part of farmer adaptation strategies to climate change. We will need to better understand the role mechanization may be playing as small farmers try to adapt, including the extent to which access to scale-appropriate mechanized services assists farmers in their efforts to adjust farming practices to increased temperature extremes and variability. For example, mechanized technology offers farmers the opportunity to speed up operations such as land preparation, planting, and harvesting in order to avoid rains or take advantage of soil moisture. Light mechanized equipment makes it possible to plant into, or harvest from, wet fields more quickly than conventional heavy machinery that requires waiting several days for fields to dry before they can be entered. Understanding these strategies and possibilities is likely to disrupt assumptions and enable new thinking about technology choice.

The need to reconcile tensions between farming and climate priorities is becoming more pressing, with implications for changing rural land use. For example, new attention is being paid to the soil's potential through "conservation agriculture," using no-till machines for carbon dioxide storage as a simple measure that can address both climate protection and food security (Amelung et al., 2020; Lal, 2004). Part of the proposed strategy for this would be through the use of "smart irrigation," recognizing that "because quality and characteristics of soils globally are very different, and the available management technologies are dissimilar, locally

[7]The COVID-19 pandemic also further highlights the integration of rural areas with the broader economy, and the important role rural areas play in caring for returning workers from urban and overseas employment.

adapted measures are required" (Using the soil's potential, 2020). Arguing that such strategies could be targeted at particularly degraded soils, there is now a need to build a database of local soil conditions across different areas and to undertake small-scale modelling of inputs and possible yield gains. This intersects with questions of technology choice and scale-appropriate machinery, and further underlines the need for the renewed attention we are advocating.

There is also renewed interest in "high-technology" approaches to development such as the application of nanotechnology to issues such as water treatment, energy storage, air pollution, and drug delivery systems (Parker & Appelbaum, 2012). Yet there are also risks with technological approaches. For example, they may bring an unwelcome return to "quick fix" thinking and the reassertion of the power of corporate interest groups, as for example in the case of the reliance of many who question climate change on the potential for emerging technologies to offset the need for mitigation and adaptation strategies in the here and now.

The rise of the phone app as an all-purpose solution to rural problems, along with the new discourse of "digital inclusion," may be just the latest example of such thinking (Ballard, 2020). It is easy to see why rural mechanization, along with a general focus on people's livelihoods in rural areas, receives less attention.

These issues highlight the need for new forms of multi-disciplinary collaboration in research and policy among social scientists, natural scientists, and engineers. For example, prompted in part by climate change and food production debates, there are signs of a renewed interest in global issues by some in the engineering profession.[8] Two studies by the UK's Institution of Mechanical Engineers (2011, 2013) have highlighted the importance of multi-disciplinary research as a direct challenge to conventional macro-agricultural models. The engineers' approach focused on crop losses, waste in value-added chains, energy use in agriculture, and consumption patterns. These perspectives may challenge and complement existing preoccupations among agricultural researchers concerned with improved varieties of crops, increases in agricultural production, and classifications based on farming systems.

4 | CONCLUSION

In this article, we retraced some of the earlier debates about rural mechanization because we believe that "history matters," particularly for policy (Table 1). Some of the lessons from these debates remain relevant. For example, from the first phase, Leontief's systems approach is useful to ensure that the outcomes of competing policy options can be modelled across different scales, and assist with constructing more holistic planning frameworks that connect technology choice with food, water, and energy.

From the second, we now need to re-engage with macro-level political economy of capital goods production, and with the micro-level innovation, resistance, and livelihoods strategies of household actors in relation to technology.

The third phase reminds us that we should pay attention to the markets and institutions that govern opportunities for people in rural areas, especially smaller farmers with increasingly fragmented farms, dispersed households, and diverse livelihoods.

Finally, from the fourth phase, we see that neither state- nor market-led mechanization policies are appropriate. Instead, equitable development requires more nuanced thinking about partnerships that involve public, private, and non-governmental sectors. Instead of the tendency to privilege private sector supply of capital goods, we need to pay closer attention both to local level demand for mechanized inputs and to the processes of small-scale innovation and entrepreneurship.

[8]An example of the potential of new conversations between engineers and social scientists attended by one of us was the "How Engineers Think" event held at Keble College, Oxford on 12–13 November, 2019. Engineers and anthropologists debated a wide range of topics that included risk and climate change, food systems, and water.

Yet today's rural areas are changing. Our older narratives are increasingly disrupted by capital goods market expansion, changing rural–urban linkages, and the stark pressures of the climate crisis. Each has implications for the promotion of more equitable rural development. To engage with these new realities we will require a stronger knowledge base from which to build policies. Indeed, we cannot afford to make policy on the basis of weak evidence. Amanor and Iddrisu (2021) remind us that past field studies of African agriculture that lacked local detail were frequently used as the basis for highly generalized and far-reaching policy decisions. All this calls for more multi-disciplinary research, and a return to what Bernstein (2006, p. 55) describes as an earlier more open, pluralistic period when development questions were analysed "from different viewpoints and yielding different interpretations." This is in contrast to today's often narrower research, conducted in academic silos, with an insufficiently historical approach and over-reliant on new types of quantitative analysis and market economics.

Since 2015, new research and policy studies have begun to pick up on some of these themes, such as contextual diversity, partnership, and technology for smaller farmers and small- and medium-sized rural entrepreneurs. The importance of small-scale and "under the radar" mechanization, the need to think more inclusively about on-farm and off-farm activities, and joined up supply chains, are increasingly acknowledged. But these studies do not go far enough, and in some cases unhelpfully perpetuate out-of-date assumptions. For example, Diao et al. (2020) place Bangladesh in the "late-adopter Asian countries" category, despite its long-standing and well-documented history of farmers adopting small pump-sets, tillers, and threshers.

If we are to design policies that can support more equitable economic growth in rural areas a new research agenda will need to pay more attention to:

- mapping and analysing the organization of production of rural capital goods in the Global South, including both large-scale manufacturing and smaller-scale rural entrepreneurship and innovation
- understanding the roles played by both large- and small-scale mechanized technologies in the provision of agricultural services and in the shaping of new forms of agrarian economy
- the role of rural mechanization in household adaptation strategies in the context of increasing climate crisis
- how savings accrued from migration are (or are not) being mobilized into productive uses, including mechanization.

These issues require a multi-disciplinary approach that combines insights from agricultural economics with those from engineering, anthropology, and other disciplines to build a stronger knowledge base that better reflects contemporary changes and priorities.

It is not only researchers who need to move beyond the established silos that limit joined up thinking and action. Decision-makers within organizations and bureaucracies can similarly find their perspectives, and therefore their ideas, restricted. As well as providing farmer-centred insights, anthropological approaches are also valuable in encouraging decision-makers and managers to think differently, as Tett (2021) has recently highlighted in the context of anthropologists working with engineers and others in corporate and public policy environments.

So, what do policy-makers now need to pay attention to? While we do not offer specific policy recommendations, since these would be highly context dependent, we can draw attention to some general principles. Most important is the need to formulate locally and nationally specific policies, to draw advice from a range of sources, and to recognize and fill gaps in the knowledge base. Only by embracing a more holistic view that engages not only with large-scale mechanization but also with the needs of smaller farmers and small-to-medium-sized entrepreneurs in rural areas can we build effective policies to support more equitable development. This will require establishing cost-effective public sector data collection systems that can capture rapidly changing mechanization trends, including through experimentation with public–private partnerships.

In short, we now need to recognize that many of our older mechanization narratives are now disrupted by the fast-changing realities faced by people in rural areas. As a result, our knowledge is in disarray, in part because the subject has been neglected for many years, but also because knowledge is fragmented by siloed research

approaches, biases in what is considered relevant, and gaps in our understanding of both the international political economy of technology production and the ground-level realities of rural people. The agenda for research and action that we propose here addresses the consequent disjuncture between what we know and what now needs to be done.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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