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The Rapid Rise of Cross-Regional Agricultural Mechanization Services in China

Jin Yang, Zuhui Huang, Xiaobo Zhang, and Thomas Reardon

Although Adam Smith (1776) and Alfred Marshall (1920) emphasized the gains from specialization that arise from the division of labor, their focus was on the manufacturing sector. Both saw farming as being on too small a scale and bereft of economies of scale, with a market that was too small and local, with too sharp a seasonality, and too quick a succession of tasks to support either the development of a division of labor over the tasks of a cropping season or of mechanization.

Smith and Marshall's vision of farming—and its implications for division of labor and mechanization—was manifest again in the 1950s to the present in Asia. Ruttan (2001) puts forward nearly the same ideas and terms as Smith and Marshall, but for contemporary small rice farms in Asia. He emphasizes that the use of machines for the series of short tasks performed on tiny farms would imply costly investment in specialized machines that small farmers would be loath to make. And even if these farmers mechanized, Ruttan posited that it would not induce a segmented and specialized farm labor market as, again, the critical mass of demand for each segment would not be present. Otsuka (2012) goes further along these lines to note that only on larger farms would the mechanization investment, at least for large machines, pay off to farmers. Thus the path to efficient mechanization must have as a first step a sharp increase in Asian farm size from the current 1–3 ha average to considerably more.

In contrast to this bleak prognosis for the Asian small farm sector to develop a division of labor and to mechanize, here we show that China with farm sizes averaging below one ha, a high degree of land fragmentation, and a decline in labor supply in the countryside since the mid-2000s (Cai and Wang 2008; Zhang, Yang, and Wang 2011) has seen steadily increasing farm output and yields over the past two decades. We argue that the contradiction can, in part, be explained by increasing mechanization. Especially since 2004, there has been rapid farm mechanization in the areas of ownership and rental, plus rapid development of farm mechanization services that combine the provision of specialized labor and the services of large harvesting machines.

We focus on the latter services, in particular, their manifestation in the emergence of a cluster of farmer companies that sell harvesting services (as harvesting is the most "heavy" of the tasks) across the provinces of China and throughout the year. By taking advantage of a national services market that includes labor and machinery, these farmer companies have overcome the constraints logically identified by the economists cited above.

The Chinese Agricultural Conundrum and Mechanization

The conundrum of labor drain and output gain in Chinese agriculture during the past three decades is explained by the rapid rise of farm mechanization, as we discuss below.

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Farm Labor Drain versus Farm Output Gain

There has been a sharp decline in the size of the rural population working in agriculture since 1978. That year is chosen because it is the start of a policy called the "household responsibility system" that led to rapid growth in farm output by creating individual incentives (Lin 1992). The size of population in agriculture dropped precipitously from about 95% in 1978 to about 70% in 1995; it dropped again gradually from 1995 to about 65% in 2010.

Two forces led to that sharp drop. The first force to reduce the size of the rural population in agriculture was rural nonfarm employment, which has developed rapidly in the past three decades. This growth has been spurred, at least in part, by the emergence of "rural industrialization." Lin and Yao (2001) note that from 1978 to 1997, the number of rural enterprises (owned by individuals and by government) jumped from 1.5 million to 20.2 million. Rural industry accounted for less than 10% of rural employment and 8% of rural income in 1978; by 1996 it was 30% of rural employment and 34% of rural income. (Note that this underestimates rural nonfarm employment, because in addition to rural industry and manufacturing, there are service sector activities.) By 1992 rural industry averaged 65% of rural output in the coastal provinces and 30% in the inland provinces. This shows that the rural industry had become increasingly important but spatially more skewed towards the coastal region. Although China's manufacturing was located almost entirely in urban factories before the 1970s, by 1997, rural industry produced 58% of China's manufacturing and 46% of its exports. Most rural enterprises were private (89% were individual or cooperative by 1986) and the remaining 80% was privatized by 1998.The majority of rural enterprises were small and labor intensive. A large number constituted rural self-employment (estimated at about 40% in the early 1990s; see Mohapatra, Rozelle, and Goodhue 2007). Lin and Yao (2001) note that the rapid rise of rural industrialization was driven by the following: (1) initiation of a program of rural industrialization communes in the 1970s to produce agricultural machinery; (2) a surge in funds from the local agricultural surplus that was driven in turn by the surge in farm output after 1978; and (3) retained earnings from rural enterprises (with bank credit playing a very minor role).

The second force that reduced the share of rural population laboring in agriculture was the massive rural-to-urban migration that occurred during the past two decades. Moreover, as China's cities grew and manufacturing and services boomed in the cities, there was a massive rural-to-urban migration during the 1990s and 2000s. Before the 1990s, the government had strict limits on urban household registration; this greatly limited the migration of rural populations to cities. Economists believed there was a strong rural labor surplus in that period (Green 2008). During the 1990s, the government gradually liberalized urban household registration restrictions, with a nearly full liberalization by the end of the 1990s. Consequently more and more rural people migrated to the cities. The migration push factor was equivalent to the size of the tiny farms (averaging is 0.17 ha per capita). So with about four persons per household, the average farm was about 0.68 ha,; the size was kept small by disallowance of farm sales and limitations (albeit gradually relaxed; Deininger and Jin 2009) on farmland rental. The migration pull factor was the rapid growth of cities and urban industry and construction. The result was that the number of rural-to-urban migrants went from around 30 million in the late 1980s to 150 to 180 million by the late 2000s (Fan 2009). Whereas rural industrialization was heavily biased toward the richer coastal regions, most of the migrants emanated from the poorer interior regions, that is, the central and southwest interior provinces (Deininger and Jin 2009).

The above chronicles a massive loss of rural people working on farms, in both the coastal and the interior provinces. The population that shifted away from farming was disproportionately younger, at the height of their earning power. One could only expect that this shift in labor to the nonfarm sector would sharply reduce the output of the millions of tiny farms that traditionally produce using labor-intensive techniques.

Yet yields in tons per hectare went from about 2.5 in 1978 to 3.5 in 2000 to 4.2 in 2010. This trend, of course, masks changes in output and input composition, but nevertheless shows a strong upward trend. Cropped area also did not decrease, rather it rose slightly during that period.

Abstracting from other sources of farm yield increase (such as the increase in fertilizer use over the period), the diffusion of farm mechanization can be used to explain why farm output did not decline as farm labor

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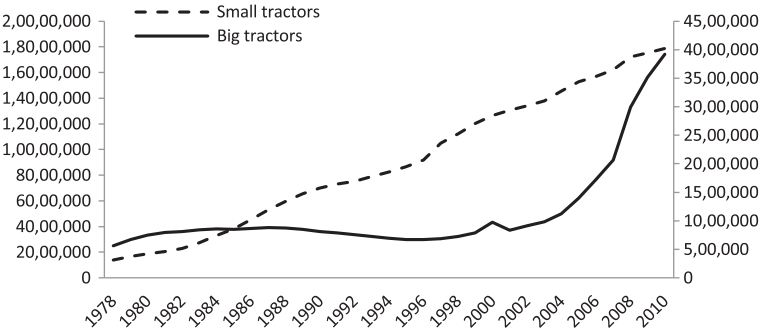

Figure 1. Number of small tractors versus big tractors

Source: Government of China (2011).

supply greatly declined. The China Statistical Yearbook (Government of China 2011) shows that from 1985 to 2009, machinery usage, proxied by kilowatts of energy expended by the machines, rose nearly seven times from about 150 million kw in 1985 to about 950 million kw in 2009. In a rough calculation, and noting that each unit of mechanical horsepower is equal to 0.75 kw (www.wowhorses.com), the latter comes to 708 million horsepower in of farm machinery 2009. A small power tiller operates on 6 hp, making it equivalent to 118 million small tillers. A small tractor may have 100 hp, so the 2009 kilowattage translates into about 7 million tractors. In any case, the increase in farm machine use was massive. Interestingly, the increase in kilowattage in machinery followed a fairly smooth trend over several decades, implying that machinery rose quickly in the 1980s and 1990s as use of off-farm labor rose; it did not suddenly rise in the mid-2000s when farm wages started to rise sharply in what has been identified as the Lewis turning point in rural China (Zhang, Yang, and Wang 2011). This suggests that rural households were facing farm-level labor constraints, in particular during the agricultural peak seasons, before these constraints translated into a significant tightening of the farm labor market. The farm-level labor constraints then presumably drove mechanization from the demand side.

From the supply side, there had been a sharp substitution of animal traction with machines. Animals used for traction, per 100 farm families, dropped from about 55 in 1985 to only 20 in 2009. As there were about 200 million farm families in China in 2009, this implies about 40 million animal traction animals. That 40 million "horsepower" can be compared with the current stock of about 700 million machine-based horsepower. A very rough calculation implies that only 5% of traction power was from animals by 2009; that is a far cry from Hopfen's (1969) estimate of 98% in 1969. Part of the displacement of animal traction is the increase in access to and reduction in the relative price of machine traction, with the rapid development of the farm machine industry in China and an increase in imports of machines from Japan and other countries.

Moreover, both the small machine and large machine stocks developed quickly. Here we take the example of the tractor, which is most relevant because it is the only machine to be available in both small and large versions; other machines (apart from combines) tend to small in Chinese farm areas. Figure 1 shows that the small tractor is extremely dominant in the tractor stock of China. In 1978 there were only 1 million small tractors; that rose to 18 million by 2010. Using government statistics, which provides a rough estimate, if one assumes 11 hp to be the size of one small tractor in 1978, it would be 11 million hp in 1978. Using the same data, it would be 13 hp per small tractor in 2010, and 234 million hp in 2010. These figures imply an increase of 21 times in the horsepower stock of small tractors from 1978 to 2010, a spectacular increase. These small tractors can be used to pull a variety of attachments, such as disk harrows, on the farmland and also serve other purposes such as transport.

In 1978 there were about 800,000 large/medium tractors. At roughly 42 hp each (per government statistics), that implies a stock of

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33.6 million in 1978 (three times the horsepower stock of small tractors). This number remained low until 2005 when it began to rise from 1 million large/medium tractors to 4 million by 2010. The total horsepower of the 2010 stock, at 38 hp per large/medium tractor (per statistics), implies 152 million hp (65% of the horsepower stock of the small tractors). There was thus a 5-fold increase in the horsepower stock of medium/large tractors over the period. This is a substantial rise, although only a quarter as fast as the rise of small tractors.

The rapid rise in ownership of small tractors is easily explained as the confluence of the rising opportunity cost of farmers' time, the small size of farms, and the relatively small investment a small tractor implies. Less obvious is why there was a rise in the demand for large/medium tractors. Several reasons explain the latter.

First, large/medium tractors are used mainly to pull large combines for rice and wheat harvesting. Harvesting is a labor- and power-intensive activity that was formerly performed manually, then with small harvesters, and only recently with a sharp increase in the use of large tractors. This may be linked to the rise of rural wages that occurred around 2004, driven apparently by off-farm employment increases (Zhang, Yang, and Wang 2011).

Second, the rise in the wage explains mechanization, but not the emergence of the use of large tractors per se. For the latter, we first compare the economics of owning a small tractor versus a large tractor for a small farmer (recall that the average farm in China is less than one ha, a bit smaller than a farm in India). The small tractor has multiple uses, as noted above, and its small size is matched by a small investment. By contrast, a large tractor is mainly used to pull a large combine harvester. Owning these large machines would not be profitable for a small farmer, as the fixed cost relative to the land holding is very high, also the large machine has limited multifunctionality.

By contrast, if the farmer has a small farm (say 1 ha) and if there is a rental market for machine services, there is significantly more reason to own a large tractor with combine (to rent it out or use it to provide services to other farmers) or to rent the services of that machine with skilled labor, rather than own a combine, large or small. By extension, there are conditions under which it is less costly for a farmer to employ the services of the tractor/combine service rather than use his own small tractor/harvesting machine (and even easier to lay out conditions under which he would rather use the rental than own the large tractor, as that is equivalent to the owner renting out the machine).

While it is possible for a large/medium tractor/combine to provide harvesting services in a local area, it may be difficult in the local catchment area to find the needed number of clients. For that reason and others discussed below, tractor/combine (harvesting and threshing) services have arisen in China where the firm sells these services in areas broader than the local area, in fact, selling throughout the provinces, to take advantage of harvests for rice and wheat that occur at different times in different provinces. As discussed in the introduction, this allows expansion of the market size and thus a division of labor, with specialized labor with large tractor/combine to realize that division. We discuss this case below.

Rise of the Interprovince Combine Service Enterprise (CSE) Cluster in Jiangsu

A cluster of farmer-owned enterprises developed in the past decade in Peixian County in the coastal province of Jiangsu. These enterprises consist of individual farmers who own a truck that pulls a large combine (for harvesting and threshing rice). Each machine owner (a farmer in Peixian) hires 3 to 4 workers and takes to the highway each year to other provinces to harvest and thresh rice. We will call these firms "combine service enterprises" (CSEs). We only discuss the CSEs that sell their services across provinces, with the exception below where we compare them with local area CSEs with which they compete.

Peixian is one of the oldest clusters of CSEs providing interprovince services. The cluster is based in an area with a dense highway network. Many farmers in this rice and wheat area bought tractors and combines in the late 1990s. Starting in 1998, the machine-owning farmers started to provide local services of harvesting others' farms. By 2011, our survey year, the services had spread to 12 provinces, including richer coastal provinces (Jiangsu, Zhejiang, Shanghai, Shandong, Guangdong); agriculturally advanced inland provinces (Heilongjiang); and inland "central region" provinces, a variety of which are migrant-sending provinces (Anhui, Chongqing, Guangxi, Sichuan, Yunnan).

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To go from farms purchasing large tractors and combines to a cluster of dynamic firms servicing a dozen provinces, and all in one decade, is a story of facing and meeting a series of challenges. We discuss those next.

Challenges Faced and Resolved in the Development of the CSE Cluster

The first challenge was the initial small size of the market (as they started locally) and thus an initially limited ability to recoup fixed costs. Gradually, starting in 1998 and during the past decade, the farmers moved from use of their own machines on their own fields to servicing other farms in the local areas in 1998 to 2002. Then, starting in 2003, selling harvesting services in 12 provinces to spread the large fixed cost. They were able to compete in other provinces based not so much on charging less than the local combine service providers they encountered there (in fact, from data we have from a farm survey in Sichuan, we find that local and interprovince services charge about the same per hectare) but by providing the service much more quickly and in a more timely fashion than the local services, according to key informants in the receiving areas.

The second challenge faced was the difficulty in transporting machinery long distances once the CSEs moved beyond their own province. Initially they used Futian (Chinese) combine-harvesters; however, they disposed of these as the machines did not stand up to being moved long distances and often broke down. They then shifted to Kubota (Japanese) large tractor-combines that were more durable, resisting the long road trips and variable terrains of clients.

The third challenge was the initially high (threshold) costs faced on a number of fronts relative to the scant resources of individual farmer-owners.

One important cost was that of the tractor and combine. A medium- to large-sized combine (harvest/thresher) from Futian Company cost about $10,000 in 1998 and can be pulled by a small truck. The Kubota equivalent machine cost about $30,000 in 2003. Moving that larger combine large distances meant farmers also needed to buy large tractors, at about $8,000 in 2003 and $15,000 in 2012. The initial outlays for the machines per farmer were much higher than farm incomes; even a rice farmer in relatively well-off Heilongjiang province earns $5,000 a year from rice sales (Reardon et al. 2010), perhaps double that as overall income.

Moreover, until 2004 there was no government subsidy for the machines. This limited initial adoption to the wealthier farm families (and extended kin who would provide loans, as bank loans were scarce) in Peixian at the start. However, as the initial CSEs demonstrated their success, the government stepped in 2004 with a subsidy (of nearly $10,000 per machine set) to help less-wealthy farmers participate in the growing cluster. Government also began subsidizing warehouses to house the machines and even provided group messaging cell phone services among the members traveling in a group. In addition, the massive government investment in road extension and improvement as well as the abolishment of highway tolls for combine harvesters was crucial to the development of the interprovince operation.

Another important cost was that of determining the demand for the services. As Peixian farmers lacked skills to perform the service and lacked information about harvest timing and needs in the other provinces, the government provided harvest calendars across regions. In the early 2000s, this was a quasi-public way of providing information and training to the CSE owner-farmers. This was important to the development of the cluster. After the CSEs proliferated and had experience in a number of provinces, their own experience supplanted the need for government information.

A further important set of costs involved the need for collective maintenance, coordination over farmers to not overlap and compete, and security in the demand areas. The CSE owners evolved a system to meet these costs by forming small cooperatives of 5 to 10 CSEs who travel together and coordinate with other small groups. Each truck brings a commonly used spare part. By pooling together, they can deal with most of the part problems.

Performance of the CSEs

In 2011 the authors conducted a survey of 101 CSEs in Peixian from 31 CSE cooperatives. Table 1 reports key results from the survey. A typical CSE services 133 ha, roughly 200 farms. A farm of that size takes roughly 2 to 3 hours to harvest, and with travel, that means a CSE can service about 2 farms a day; that is roughly 100 days (more than three months) on the road. This means that a given CSE services several provinces, moving north or south to cover different harvest times. The average CSE charges roughly $272 (also its gross income)

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Table 1. Income and Cost of Combine Service Enterprise Survey in Peixian

Income/cost	Median	Percent	Obs	CV
1. Net income, $	13,492		110	0.59
2. Total costs, $	22,699	100		
a) repair and maintenance	3,175	14	109	0.79
b) employee wages	7,143	31	91	0.59
c) telephone	318	1	110	0.59
d) food/lodging while traveling	4,921	22	64	0.34
e) gasoline/diesel	7,142	31	106	0.46
3. Area served, hectares	133		97	0.67
4. Costs per hectare served	171			
5. Gross income per hectare	272			
6. Net income per hectares	101			

Notes: Calculated by authors based on authors' survey. CV, coefficient of variation; Obs, number of observations.

per hectare served, with costs of $171 (a third on fuel, a third on wages, and the rest on lodging and maintenance) and net earnings of $101/hectare. This is a net income from the CSE activity of $13,000. (This is an overestimate because it does not net out amortization of the equipment). This can be roughly compared with the total sales of a rice farm in Heilongjiang province in 2009, about $5000. Also that is an underestimate because the total farm household income includes sales of other crops and nonfarm income; however, it provides a rough comparison to show that the CSEs are earning well from this activity.

Conclusions

Despite small farm sizes, high land fragmentation, and wage escalation, agricultural production in China has steadily increased in the past several decades. Here, we posit that interregional mechanization services can, in part, help explain the puzzle. In response to a rising wage rate, the most power-intensive stages of agricultural production, such as land preparation and harvesting, have been increasingly outsourced to special service providers. Tens of thousands of private mechanization service providers travel throughout the country to harvest crops. To illustrate this development, we presented a case study of such interregional services based on our primary survey of a cluster of CSEs in Jiangsu Province. The case study showed the cluster's development leading to a wide-ranging supply throughout 12 provinces for much of each year, competing with local services with rapidity and coordination.

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