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IFPRI Discussion Paper 01415

February 2015

Mechanization Outsourcing Clusters and Division of Labor in Chinese Agriculture

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ABSTRACT

Most of the poor in the developing countries are smallholder farmers. Improving their productivity is essential for reducing poverty. Despite small landholdings, a high degree of land fragmentation, and rising labor costs, agricultural production in China has steadily increased. If one treats the farm household as the unit of analysis, it would be difficult to explain the conundrum. When seeing agricultural production from the lens of division of labor, the puzzle can be easily solved. In response to rising labor costs, farmers outsource some power-intensive stages of production, such as harvesting, to specialized mechanization service providers, which are often clustered in a few counties and travel throughout the country to harvest crops at very competitive service charges. Through such an arrangement, smallholder farmers can stay viable in agricultural production.

Keywords: agriculture; Lewis turning point; outsource; mechanization

JELcodes: J31 O12

ACKNOWLEDGMENTS

The authors would like to acknowledge the support from China Natural Science Foundation and China (71350002) and National Social Science Foundation (13CGL085). Without the help of Song Guo and Sihua Li, our survey on the service providers of combine harvesting in Peixian would not have been possible. The authors are also grateful for the helpful comments from participants at the seminars, in particular Arnab K. Basu, Hung-Hao Chang, Nancy Chau, Yanyan Liu, Frank Lo, Tim Mount, Mitch Renkow, Walter N. Thurman, and Xiaoyong Zheng, given at Cornell University, North Carolina State University, and National Taiwan University.

1. INTRODUCTION

In the *Wealth of Nations* (Smith 1776), Adam Smith emphasized the gains from specialization arising from the division of labor. He famously illustrated this with pin making in a workshop, where ten workers, each doing a specialized task of the set of tasks to make a pin, could make hundreds of times more per day than the ten workers working independently, each doing all the tasks. He also posited that market size determines the division of labor. If the volume of demand is too small, worker specialization would not pay, and each of the few workers in a firm or farm would need to be a "jack of all trades."

Smith believed that 18th- and 19th-century European manufacturing, with its integration into wide national and international markets, promised and realized the combination of division of labor, market development, and mechanization. By contrast, he saw farming as of too small a scale and bereft of economies of scale, with a market 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 mechanization. For instance, Smith stated the following in the *Wealth of Nations*:

> *"The nature of agriculture, indeed, does not admit of so many subdivisions of labour, nor of so complete a separation of one business from another, as manufactures. It is impossible to separate so entirely the business of the grazier from that of the corn-farmer as the trade of the carpenter is commonly separated from that of the smith... the ploughman, the harrower, the sower of the seed, and the reaper of the corn, are often the same. The occasions for those different sorts of labour returning with the different seasons of the year, it is impossible that one man should be constantly employed in any one of them. This impossibility of making so complete and entire a separation of all the different branches of labour employed in agriculture is perhaps the reason why the improvement of the productive powers of labour in this art does not always keep pace with their improvement in manufactures."*

Marshall (1920, 167) echoed Smith's viewpoints in his *Principles of Economics*:

> *"In agriculture there is not much division of labour, and there is no production on a very large scale; for a so-called 'large farm' does not employ a tenth part of the labour which is collected in a factory of moderate dimensions."*

The latter vision of farming—and its implications for division of labor and mechanization—was manifest again in Asia from the 1950s to the present. Ruttan (2001, 190) puts forward nearly the same ideas and terms as Smith and Marshall, but for contemporary small rice farms in Asia:

> *"The seasonal characteristic of agricultural production requires a series of specialized machines—for land preparation, planting, pest and pathogen control, and harvesting—specially designed for sequential operations, each of which is carried out only for a few days or weeks in each season. This also means that it is no more feasible for workers to specialize in one operation in mechanized agriculture than in pre-mechanized agriculture. In addition, in a 'fully mechanized' agricultural system, because of the mobility and specialization characteristic, investment per worker is generally much higher than that in industry."*

Ruttan emphasizes that using machines for the series of short tasks on tiny farms would imply costly investment in specialized machinery that small farmers would be loath to make. While recognizing the important role of mechanization in various steps of agricultural production, Pingali (2007, 2790) holds a similarly pessimistic view on rice harvesting mechanization in Southeast Asian countries:

> *"In the absence of land consolidation and the re-design of the rice land to form large contiguous fields, the prospects for large-scale adoption of the harvester-combines are limited."*

Otsuka (2012) goes further along those lines to note that only on larger farms would the mechanization investment, at least for large machines, pay off to farmers—and thus the path to efficient mechanization must have as a first step a sharp increase in Asian farm size from the current 1 to 3 hectare (ha) average to considerably more. Given that China's farm size is only one-third that of Japan's, he warned that Chinese agriculture would likely repeat the path of Japan to rely heavily on subsidies and experience low growth in labor productivity.

Standing in contrast with the above prognosis for the Asian small farm sector to develop a division of labor and to mechanize, this paper shows that China—with farm sizes averaging only about 0.5ha—has both evolved a division of labor in the farm sector and experienced rapid farm mechanization. There is a paradox: despite the rapid decline of labor supply in the countryside, China has seen steadily climbing farm output and yields over the past three decades. We show that the explanation of the paradox is that since circa 2004, there has been rapid farm mechanization in the form of both ownership and rental of machines, plus rapid development of farm mechanization "outsource" services that combine the provision of specialized labor and the services of large harvesting machines.

This paper focuses on the latter services in China, and in particular the manifestation of them in the emergence of a cluster of farmer cooperatives that sell these harvesting services (as harvesting is the most "heavy" of the tasks) across provinces for up to eight months a year. By availing of a national labor-cum-machine services market, these migratory specialized mechanization service providers have overcome the small scale of agricultural production at the farm level logically identified by the economists cited above. This has precedent, for example, in the US, where migratory beekeepers provide pollination services to commercial fruit and nut producers (Chang 1973, Muth et al. 2003).

Our paper makes two contributions. First, the paper shows that, for China, agricultural production can be as divisible as industrial production; this point has been largely neglected in the history of economic thought. When looking at production of small farmers from this lens, farm size will become a less limiting factor to scale of production if some steps of production can be out-sourced. Although our paper is about China, the findings may shed some light on the debate as to whether smallholder farmers are efficient in developing countries in general and countries in Africa south of the Sahara in particular, a topic much debated recently, for example by Collier and Dercon (2013).

Second, the paper contributes to the literature on agricultural mechanization. In the 1980s there was a wave of literature on mechanization and farming systems change in the wake of the Green Revolution (for example, Binswanger 1986, Jayasuriya and Shand 1986,and Jayasuriya et al.1986). After a mainly dormant period of some three decades, there has been a second wave of literature on mechanization (for example, Takahashi and Otsuka 2009, Pingali 2007, and Diao et al. 2012). An important motivation for the second wave of literature has been, as for example Takahashi and Otsuka note, that a spur to and acceleration of mechanization have been driven, on the capacity side, by investment from the investable surplus from the Green Revolution and in labor market development from the rapid spread of rural nonfarm and migration employment, and on the incentive side, by the rural wage increase prompted by this labor market development. This second wave has treated the surge in machine ownership and conventional rental, but not yet the relatively new arrangement of outsourced services provided pan-territorially and pan-seasonally by clusters of service providers, as has been the case in China over the past decade.

The paper proceeds as follows. Section 2 explores in greater detail the three trends noted above. Section 3 explains the economics of mechanization harvesting services. Section 4 describes the supply of mechanization services based on a primary survey in Peixian County in Jiangsu province. The survey covers farmer cooperatives supplying migratory labor-cum-machine services to a number of provinces in China. Section 5 concludes.

2. THE CHINESE AGRICULTURAL PARADOX AND MECHANIZATION

There is a paradox in Chinese agriculture in the past three decades—despite the small farm size and massive exodus of labor out of agricultural production, farm output has steadily gained over time. This section explores and explains this paradox and its relation to mechanization.

Farm Labor Drain

In 1978, more than 92 percent of the Chinese population worked in agriculture, on farms; this rural population density and high share of population in agriculture was partly because the country was much poorer at that time (and the share of population in agriculture is typically inversely related to countries' income per capita; see Timmer 1988) and partly due to the restriction of labor mobility by the household registration system implemented in the 1950s (Lin et al. 2008).

Although rural population density is still relatively high, and farms average about 0.5 hectare (one of the lowest in the world), from 1978 to today, there has been a massive drop in the share of the population operating farms. The Organization for Economic Co-operation and Development (OECD) estimated that 40 percent of China's labor was in agriculture in 2005 (McGregor 2005). This has happened for three reasons.

First, in the past three decades there has been a rapid rise in rural nonfarm employment, complementing farm household incomes but also pulling labor time from farms and farm households out of farming. This 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 was less than 10 percent of rural employment and 8 percent of rural income in 1978; by 1996 it accounted for 30 percent of rural employment and 34 percent of rural income. (Note that this underestimates rural nonfarm employment because in addition to rural manufactures there is also substantial rural service sector activity.)

Second, as China's cities grew and manufactures and services boomed in the cities, there was a massive rural to urban migration over the 1990s and 2000s. Before 1990, the government had strict limits on urban household registration, greatly blocking rural migration to cities (Green 2008). During the 1990s, the government gradually liberalized urban household registration restrictions, with a nearly full liberalization by the end of the 1990s. Beside this "rural labor release" factor, there was a push factor for migration, to wit, tiny farms, kept small by disallowance of farm sales and limitations on land rental.1 There was also a large pull factor for migration—the rapid growth of cities and urban industry and construction. The result was that the stock of rural-to-urban migrants went from around 30 million in the late 1980s to 150–180 million by the late 2000s (Fan 2009).

Third, China's stringent one child policy introduced in the late 1970s caused the natural population growth rate to decline from 2.58 percent in 1970 to 0.48 percent in 2012. As a result, China's working-age labor force, including in rural areas, started to shrink in 2012.[2]

That shift of labor out of agriculture incited many media reports on labor shortages. It also induced wage increases: Zhang et al. (2011) report that real wages started to accelerate in 2003/04, suggesting that the era of Lewis-type surplus labor had come to an end.[3]

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[1]Deininger and Jin (2009) note, however, that these rental limitations were gradually reduced in the 2000s.
[2]www.economist.com/blogs/freeexchange/2012/01/chinas-labour-force.
[3] For the original idea, please refer to Lewis (1954).

Farm Output Growth

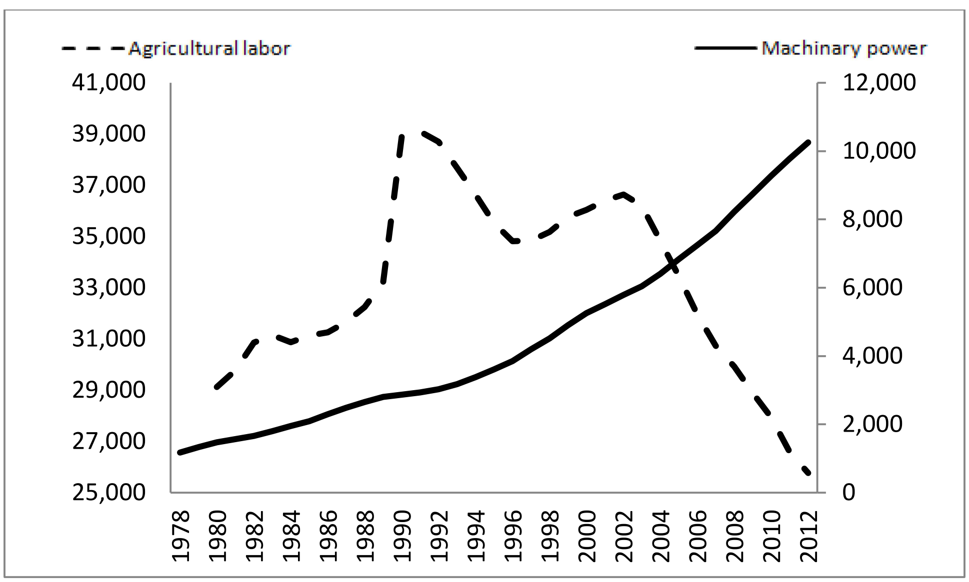
The above chronicles a massive loss of rural people working on farms, in both the coastal and the interior provinces. This was not much compensated by rural population increase. Moreover, most of those who left farming were younger workers, the most physically productive. One could only expect that this shift in labor to the nonfarm sector would sharply reduce the output of the millions of tiny farms traditionally producing with labor-intensive techniques.

Contrary to that expectation, crop yields in tons per hectare went up from about 2.5 in 1978 to 4.3 in 2000 to 5.3 in 2012 (NBS 2012). Wheat, rice, and maize yields increased rapidly, by 70 percent, 70 percent, and 109 percent, respectively, in the same period.

The Puzzle Explained: The Rapid Rise of Farm Mechanization

Figure 2.1 shows that from 1985 to 2012, farm machinery usage, proxied by kilowatts (kW) of energy expended by the machines, rose sevenfold, from about 150 million kW in 1985 to more than 1billion kW in 2012. In a rough calculation, and noting that each unit of mechanical horsepower (hp) is equal to 0.745699872 kW, 1 billion kW comes to about 750 million hp of farm machinery. A smaller power tiller operates on 6 hp, so that would mean the equivalent of 118 million small tillers. In any case, the increase in farm machine use was massive. Interestingly, the increase in machinery use was a fairly smooth trend over those decades, implying that machinery use was rising quickly in the 1980s and 1990s as off-farm labor use rose. Yet that rise of machine use did not accelerate in the mid-2000s, when farm wages started to rise sharply in what has been identified as the Lewis turning point in China (Zhang et al. 2011). This suggests that rural households were facing farm-level labor constraints in the agricultural peak seasons before the arrival of the Lewis turning point.

Figure 2.1 Number of agricultural workers and machinery power



Source: Data come from the *China Statistical Yearbook* (NBS 2011).
Note: Unit of machinery power is 100,000 kW.

The above juxtaposed trends suggest a hypothesis that there has been a substitution of machinery for labor in farming. To test that hypothesis, we need to control for the use of other farm inputs (beyond labor and machines) and test for the impact of mechanization on agricultural production. For this, we use provincial-level data from 1979 to 2010 to estimate a Cobb-Douglas grain production function as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (1)$$

where y, x_1, x_2, x_3, and x_4 are total grain output, cropping area, labor input, owned machinery power, and fertilizer input, respectively, at the provincial level in each year. All the variables are in logarithmic form.

Table 2.1 reports the estimation results. The regression in column 1 follows the specification of equation (1). In regression 2, we add province fixed effects. Year fixed effects are considered in regression 3. Regression 4 includes both province and year fixed effects. Regression 4 has the smallest AIC, indicating it is the best specification among the four regressions. The data used are from the *China Rural Statistical Yearbooks*.

Table 2.1 Estimation of an agricultural production function based on data at the provincial level

Variable	R1	R2	R3	R4
Land	0.653***	0.926***	0.619***	0.987***
	(0.06)	(0.06)	(0.07)	(0.08)
Labor	0	-0.095	0.001	-0.086
	(0.08)	(0.07)	(0.08)	(0.07)
Machinery capital	-0.012	0.047	0.012	0.026
	(0.06)	(0.04)	(0.07)	(0.06)
Fertilizer	0.355***	0.309***	0.368***	0.243***
	(0.08)	(0.05)	(0.10)	(0.06)
Province dummy	no	yes	no	yes
Year dummy	no	no	yes	yes
N	945	945	945	945
R2_a	0.971	0.993	0.971	0.993
AIC	-423	-1,763	-406	-1,834

Source: China Statistical Yearbook (NBS 1978–2010).

Note: The dependent variable and independent variables are in natural logarithmic form. Standard errors are clustered at the provincial level. The symbols *, **, and ***represent levels of significance at 10 percent, 5 percent, and 1 percent, respectively.

Several results are salient. The coefficient for land is positive and significant in all the regressions. Land elasticity is around 0.95 when province fixed effects are included. Fertilizer also contributes to grain production, although its elasticity is smaller than that of land. The coefficient for labor is statistically insignificant. The mechanization variable's coefficient is positive but not statistically significant. Given the rapid increase in machinery power, at first glance, this machinery result seems to support the view that mechanization does not work well for small farms. We suspect the insignificant coefficient has something to do with the definition of the mechanization variable in the *Yearbooks*. Ideally, we should use the actual machinery use, but those data are not available at the provincial level; instead, only total owned machinery power at the provincial level is published in the *Yearbooks*.

Mechanization services provided to farmers who do not own machinery, by outside sourcing, could be so important as to be a large factor missing from regressions based on the *Yearbook* data. To test this hypothesis, we used data from the yearly household survey done by the Research Center for the Rural Economy (RCRE) of the Ministry of Agriculture. The RCRE dataset includes detailed information on actual input use in agricultural production. Machinery use was added to the questionnaire in 2004. In the empirical analysis, we use yearly data available to us from 2009 to 2012, covering 49,301 households.

Table 2.2 presents the summary statistics of the output and input variables used in the regressions. Total grain output (in value terms) per farm household has increased on average by 13 percent per year from 2009 to 2012. The average farm expanded by 4 percent per year, from 0.49 ha to 0.54 ha. Thus, most of the increase in grain output is from increasing use of non-land inputs or total factor productivity improvement or both. In the same period, labor input actually declined from 85 days to 80 days. The reduced labor input was compensated for by the increase in other inputs, mainly fertilizers, pesticides, and machinery. The expenditure on machinery use jumped by 66 percent from US$66 per ha to US$110, with an annual growth rate of 18 percent. The outlay on seed, fertilizer, pesticide, and irrigation grew mostly at lower rates, 19 percent, 14 percent, 14 percent, and 3 percent, respectively. It appears that the expenditure on non-land inputs has offset the decline in labor use.

Table 2.2 Average agricultural production and input at the household level

Variable	2009	2010	2011	2012	Annual growth rate (percent)
Total					
Output($)	492.29	517.88	632.18	704.24	0.13
Land size (hectares)	0.49	0.50	0.52	0.56	0.04
Labor input (days)	85.42	84.84	81.98	80.21	-0.02
Machinery fee ($)	66.30	72.75	86.00	110.08	0.18
Seed fee ($)	36.21	42.06	49.98	61.30	0.19
Fertilizer outlay ($)	122.76	125.78	150.68	181.19	0.14
Pesticide outlay ($)	23.49	25.53	28.77	34.95	0.14
Irrigation outlay ($)	36.53	30.54	32.61	40.22	0.03
Wheat					
Output (kilograms)	1416.48	1465.32	1494.52	1505.23	0.02
Land size (hectares)	0.27	0.27	0.27	0.27	0.01
Labor input (days)	42.47	43.11	43.57	40.91	-0.01
Machinery outlay ($)	41.82	48.07	51.24	61.13	0.13
Seed outlay ($)	24.03	27.70	29.61	30.76	0.09
Fertilizer outlay ($)	61.69	68.28	77.75	89.52	0.13
Pesticide outlay ($)	7.38	8.89	10.40	12.64	0.20
Irrigation outlay ($)	23.04	18.73	19.76	24.03	0.01
Rice					
Output (kilograms)	2126.42	2017.00	2252.52	2456.94	0.05
Land size (hectares)	0.30	0.30	0.32	0.33	0.03
Labor input (days)	68.90	68.15	65.33	65.41	-0.02
Machinery outlay ($)	50.74	54.99	70.90	86.93	0.20
Seed outlay ($)	18.06	20.65	26.20	30.20	0.19
Fertilizer outlay ($)	80.63	79.01	91.74	105.82	0.09
Pesticide outlay ($)	25.84	29.12	33.01	42.34	0.18
Irrigation outlay ($)	19.56	18.77	25.57	28.63	0.14
Maize					
Output (kilograms)	2660.75	2846.93	3338.67	3876.70	0.13
Land size (hectares)	0.36	0.38	0.41	0.45	0.08
Labor input (days)	52.13	54.17	53.39	52.79	0.00
Machinery outlay ($)	36.00	40.57	49.24	70.26	0.25
Seed outlay ($)	27.26	32.86	40.36	52.19	0.24
Fertilizer outlay ($)	89.33	94.28	119.70	146.05	0.18
Pesticide outlay ($)	11.15	12.01	14.02	17.46	0.16
Irrigation outlay ($)	18.66	19.57	19.87	27.44	0.14

Source: Calculated by authors based on the RCRE household surveys (2009-2012).
Note: The values are constant at 2009 US$.

Using the RCRE dataset, we estimated a Cobb-Douglas production function similar to Table 2.1 and present the estimation results under four specifications in Table 2.3.This table differs from Table 2.1 in that the analysis is at the household level, whereas Table 2.1 is at the provincial level. The first specification in Table 2.3 is an ordinary least square (OLS) regression without either province or year fixed effects. In the second, province fixed effects are controlled for; in the third, year fixed effects rather than province ones are included. The fourth shows both province and year fixed effects.

Among the 49,301 farm households, 1,528 households own agricultural machinery valued at more than10,000 yuan yet do not have any machinery outlays for their own farms. We treat these households as mechanization service providers. Considering that they have used their own machinery for their own farms, we imputed their own outlays of machinery use on their own land by using the median machinery expenditure per hectare in their village.[4]As a robustness check, in column 5, we drop the 1,528 observations from the households with large equipment holdings but only imputed information for their own use of it.

The results are rather similar across the five specifications. Land has the largest elasticity with respect to grain output (more than 0.36), followed by labor, fertilizer, pesticide, machinery use, and irrigation. However, the coefficient for land is smaller than in Table 2.1, probably because the RCRE survey has a more accurate account of actual labor use in agricultural production at the household level. The coefficient for labor is not statistically different from zero, similar to the result of the provincial-level analysis as shown in Table 2.1.

The results suggest that mechanization plays an economically significant role in powering agricultural production growth. Among the five regressions, the last two regressions with the specification of both province and year fixed effects have the best fit, as indicated by its smallest AIC, while the second specification including only the province fixed effect performs second best. In both of these two specifications, the coefficient for machinery is significantly positive. Based on the coefficient shown in the last column, increased machinery use has contributed to 17 percent[5] of the increase in total grain output from 2009 to 2012.

If machinery inputs are mainly provided by tractors and combines available in the same province, then we should not expect to see a discrepancy between the household- and the provincial-level analyses. Therefore, the observed difference implies that farm households have likely rented in mechanization services provided by people from outside their own provinces.

[4] The sample is representative at the provincial level. Within a province, the village is the primary sampling unit (PSU).

[5] (0.121*ln(110.08/66.30)/ln(704.24/492.29)).

3. ECONOMICS OF CROSS-REGIONAL MECHANIZATION SERVICES

In this section, we analyze the economic mechanism behind the flourishing cross-regional mechanization services from both the supply and the demand side.

For simplicity, assume an average farm household operates one acre of land. If using traditional farming, the cost of labor input for each acre of land is w. For hiring cross-regional mechanization services, the price is p for T unit of service per acre. The demand for mechanization services is:

$$\begin{cases} D = T, & if \quad p \le w \\ D = 0, & if \quad p > w \end{cases} \tag{2}$$

On the supply side, let us assume the fixed cost for each unit of machinery is c_0, and the variable cost is α, such as fuel, maintenance, and living costs. The variable cost is assumed to be proportional to the total areas serviced, $c_1 = \alpha m$, where m is the total number of farm households served. Then the total supply of mechanization services is:

$$\begin{cases} S = mT, & if \quad p \ge c_0/m + \alpha \\ S = 0, & if \quad p < \frac{c_0}{m} + \alpha \end{cases} \tag{3}$$

Hence, only when, $c_0/m + \alpha \le p \le w$ holds does the market for cross-regional mechanization services emerge. Only when there are enough farms (m) to hire the service, there is a possibility for the market to exist. The minimum number of farms is determined by $c_0/m^* + \alpha = w$, or

$$m^* = c_0/(w - \alpha) \tag{4}$$

This is the minimum feasible scale over which to spread the cost of machinery, as suggested in Jayasuriya et al. (1986). We can draw several predictions from the above exercise.

Hypothesis 1: The minimum feasible scale of mechanization services is positively correlated with the cost of machinery (c_0).

Combines are generally much more expensive than plows, which are attached to tractors. For example, rice combines cost between $11,000 and $25,000. In comparison, a plow is normally less than $1,000. As a result, those who own combines are more likely to travel to sell services a farther distance over a longer period to recoup the cost than are those with plows. As a matter of fact, the plowing market is primarily local. In the RCRE 2013 survey, we attached a supplementary survey on the use of machinery in rice, wheat, and maize production in six provinces in 2012 and 2008.[6] Table 3.1 shows the prevalence of machinery use in land preparation, planting, and harvesting in China. If a farmer uses machinery, we further ask whether the machinery is on a contract-hire basis. Take rice as an example. In 2012, 86 percent of farmers used machinery for plowing, while 74 percent of rice farmers employed combine harvesters. 99 percent of the harvesting combines were used on a contract-hire basis. By comparison, among those who used mechanical plows, 82 percent of them rented in the service, a rate lower than the hire-in rate of harvesting service. Because plows are cheaper than combines, more farmers own disc plows than combines. Apart from self-use, those who own plows also provide land preparation services to other farmers in their own or neighboring villages.

[6] We randomly selected 100 households from each of the 11 major cereal-production provinces (Hebei, Liaoning, Jiangsu, Anhui, Fujian, Jiangxi, Shandong, Hubei, Hunan, Sichuan, and Shannxi provinces). The final effective sample size is 1,094.

Table 3.1 The use of machinery in Chinese agricultural production

Year	Variable	Rice		Wheat		Maize	
		Using machinery	Hiring mechanization service	Using machinery	Hiring mechanization service	Using machiner y	Hiring mechanization service
2012	Plow	86	82	90	83	62	74
	Plant	10	91	68	89	48	63
	Harvest	74	99	86	98	28	99
2008	Plow	72	80	89	82	55	70
	Plant	6	96	65	88	41	67
	Harvest	52	98	80	97	14	94

Source: Based on a complementary module of RCRE survey (2013).
Note: The numbers in the column "Using machinery" represent the percentage of farm households who have used machinery. The figures in the column "Hiring mechanization service" stand for the percentage of hiring mechanization among those who used machinery.

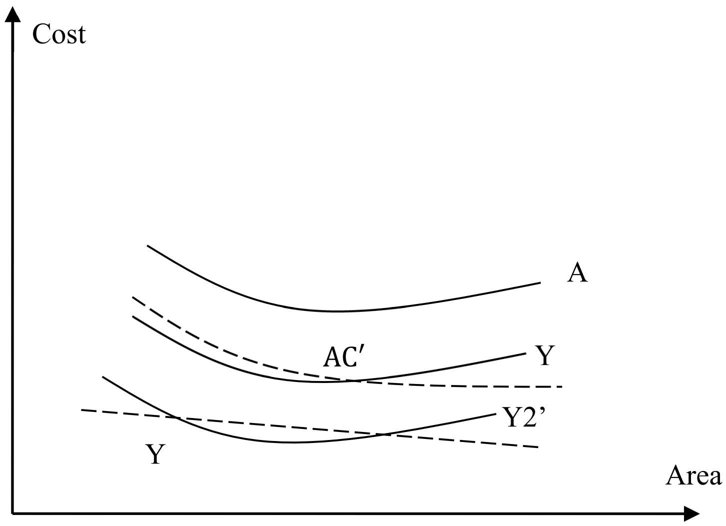
Hypothesis 2: Cross-regional migratory harvesting service is more likely to occur in countries with large seasonal variation and more flat land.

Seasonality is a defining feature of agricultural production. The time for harvesting is often constrained to a narrow window, sometimes as short as a few days, by imminent rain or pest invasion. While it is possible for a large/medium tractor/combine to provide harvesting services in the local area, it may be difficult for it in the local catchment area to find the needed number of clients in such a short harvesting window" period. In a small country without much variation in production seasons, then it would be hard to develop a viable national labor-cum-machine service market because of the limited number of days available for harvesting. However, China is large with big regional differences in cropping periods in terms of number of seasons in a year and length of a given season. For instance, there are up to three production seasons in some parts of southern China, while northeastern China crops only one season. By taking advantage of harvests for crops at different times and locations, the service providers can travel all over China to chase production seasons to maximize the number of working days and harvesting areas. Only when m exceeds m^*do labor-cum-machine services become a viable business model. This allows the expansion of the market size, and thus a division of labor—with specialized labor-cum-large tractor/combine used to realize that division.

The above is explained by the insight of Stigler (1951) that the division of labor is limited by the extent of the market. We can further use a diagram to illustrate Stigler's point. For simplicity, assume there are only two steps in production, non-harvesting and harvesting. Following Stigler (1951), we plot the average cost curve of the two steps (Y_1 and Y_2) in Figure 3.1. If a farmer finishes both steps by himself/herself, the total cost curve would be AC, the sum of Y_1 and Y_2. Suppose now a cheaper cross-regional harvesting service is available and Y_2' is the new average cost curve for renting in the mechanization services. Y_2' is below the previous Y_2. Consequently, the average cost curve moves down, as shown by the dashed line AC'. Therefore, by hiring in labor-cum-machine harvesting services, it is possible for small farmers to stay in business despite a small production scale.

Because it is more difficult to use machinery on hills than on plains, the share of flat areas will determine the size of the machine plowing and harvesting market for a given crop. Compared to rice and wheat, maize is more likely to be planted on hilly areas in China. The penetration rate of mechanized plowing for wheat in 2012 was 78 percent, higher than for maize (61 percent). Wheat harvesting relied heavily on combine harvesters (75 percent), most of which were labor-cum-machine services (98 percent). In comparison, the incidence of maize mechanized harvesting is only 31 percent. The popular models of maize combine harvesters in the US, which have strict requirements on the height and row spacing of maize, do not apply well to China because smallholder farmers use diverse seeds and do not follow some US farming practices, such as row spacing. Some Chinese maize combine harvesters adapted to Chinese cropping patterns have been developed, but they did not go on the market until recently.

Figure 3.1 The demand for mechanization services



Source: Drawn by authors based on Stigler (1951).

To further test the differential contributions of machinery use to rice, wheat, and maize, we repeat the regressions in Table 2.3 by replacing the total crop output value with wheat, rice, and maize output, respectively. The regression results are presented in Tables 3.2, 3.3, and 3.4. The coefficient for machinery is significant in all the three tables. It explains 77 percent, 31 percent, and 10 percent of the actual increase in wheat, rice, and maize output, respectively, from 2009 to 2012, reflecting the difference in machinery applications in plowing, planting, and harvesting across the three crops.

Table 3.2 Product function estimation for wheat output based on household data

Variable	R1	R2	R3	R4	R5
Land	0.454***	0.477***	0.436***	0.452***	0.452***
	(0.07)	(0.10)	(0.07)	(0.10)	(0.10)
Labor	-0.014	0.003	-0.015	0.001	0.002
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Seed	0.068	0.119**	0.07	0.126***	0.128***
	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)
Fertilizer	0.346***	0.250***	0.353***	0.258***	0.256***
	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)
Pesticide	0.044	0.04	0.050*	0.049	0.05
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Irrigation	0.012	0.032	0.012	0.029	0.029
	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)
Machinery use	0.127***	0.109***	0.131***	0.115***	0.115***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Province dummy	no	yes	no	yes	yes
Year dummy	no	no	yes	yes	yes
N	18524	18524	18524	18524	17983
r2_a	0.897	0.908	0.898	0.91	0.908
AIC	8036.547	5854.347	7808.706	5581.047	5497.298

Source: Calculated by authors based on the RCRE household surveys (2009-2012).

Note: Dependent variable and independent variables are function of natural logarithm. Robust standard errors are in parentheses. The symbols *, **, and *** represent levels of significance at 10 percent, 5 percent, and 1 percent, respectively.

Table 3.3 Product function estimation for rice based on household data

Variable	R1	R2	R3	R4	R5
Land	0.691***	0.650***	0.688***	0.646***	0.647***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Labor	-0.047	-0.025	-0.049	-0.026	-0.025
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Seed	0.032	0.035*	0.036	0.040**	0.039*
	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)
Fertilizer	0.098**	0.139***	0.096**	0.137***	0.137***
	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)
Pesticide	0.046*	0.060**	0.046*	0.060**	0.061**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Irrigation	0.025***	0.017**	0.025***	0.017**	0.017**
	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
Machinery use	0.092***	0.081***	0.093***	0.083***	0.082***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Province dummy	no	yes	no	yes	yes
Year dummy	no	no	yes	yes	yes
N	24030	24030	24030	24030	23627
r2_a	0.908	0.919	0.909	0.919	0.917
AIC	6876.257	3838.563	6800.385	3765.018	3677.664

Source: Calculated by authors based on the RCRE household surveys (2009-2012).
Note: Dependent variable and independent variables are function of natural logarithm. Robust standard errors are in parentheses. The symbols *, **, and *** represent levels of significance at 10 percent, 5 percent, and 1percent, respectively.

Table 3.4 Product function estimation for maize based on household data

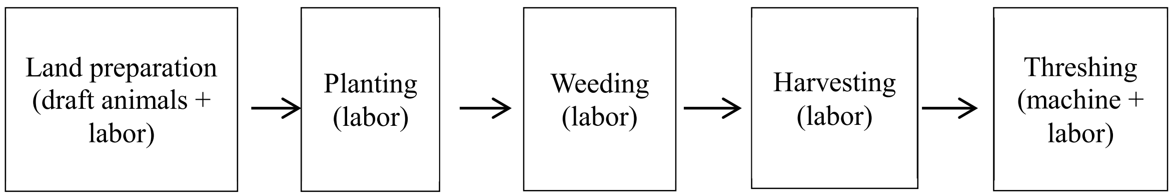
Variable	R1	R2	R3	R4	R5
Land	0.513***	0.465***	0.505***	0.457***	0.457***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.08)
Labor	-0.022	0.003	-0.023	0.002	0.004
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Seed	0.129***	0.179***	0.134***	0.185***	0.187***
	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)
Fertilizer	0.340***	0.279***	0.340***	0.280***	0.276***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Pesticide	0.040*	0.037*	0.040*	0.037*	0.035*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Irrigation	0.02	0.011	0.021	0.012	0.011
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Machinery use	0.047**	0.055**	0.049**	0.056**	0.057**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Province dummy	no	yes	no	yes	yes
Year dummy	no	no	yes	yes	yes
N	30432	30432	30432	30432	29287
r2_a	0.928	0.937	0.929	0.938	0.933
AIC	21423.753	17317.768	21410.271	17300.553	16872.162

Source: Calculated by authors based on the RCRE household surveys (2009-2012).
Note: Dependent variable and independent variables are function of natural logarithm. Robust standard errors are in parentheses. The symbols *, **, and *** represent levels of significance at 10 percent, 5 percent, and 1 percent, respectively.

Hypothesis 3: The spread of labor-cum-machine services is associated with an increase in real wages.

As real wages rise, the demand for labor-cum-machine services increases. Using rice production as an example, we show there is a fine division of labor in agricultural production, which may evolve over time in response to rising wages. Traditionally, rice production follows the steps illustrated in Figure 3.2.

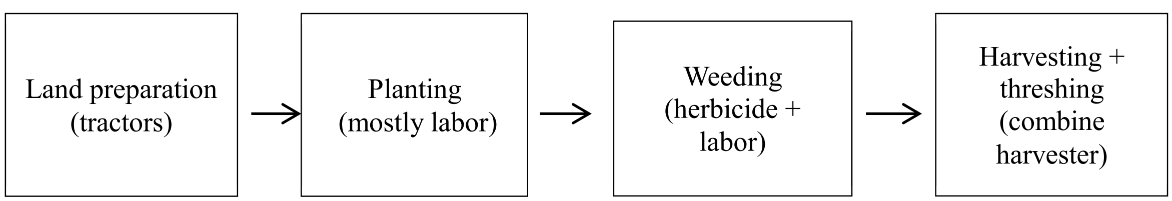
Figure 3.2 Production cycle from land preparation to harvesting then threshing



Source: Authors' creation.

When there are limited nonfarm job opportunities and labor is cheap, farmers work on most of the steps above by themselves or hire workers. However, as labor costs rise, farmers tend to source the power-intensive steps from labor-cum-machine services, such as land preparation and harvesting. In doing so, the young family members can migrate or work locally in nonfarm jobs that pay more than farm work, while the elderly family members can stay home to take care of the lighter tasks, such as weeding and irrigating crops. As a result of wage increases then, the mode of rice production has transformed (Figure 2.3).

Figure 3.3 Production cycle from land preparation to combined harvesting and threshing



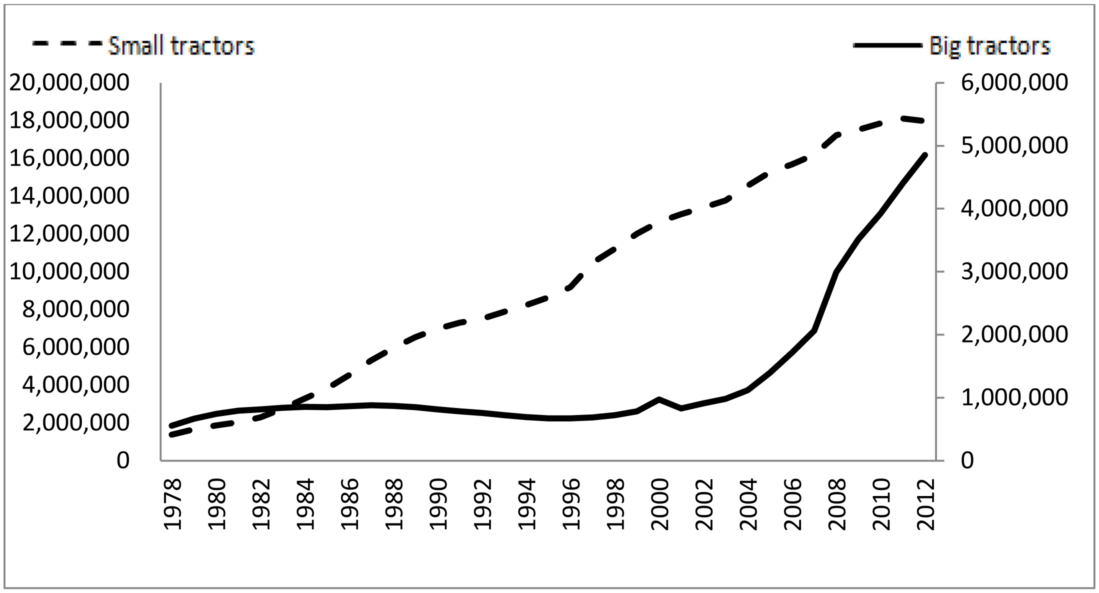
Source: Authors' creation.

In China, transplanting rice seedlings is the main way rice is planted. Transplanting requires less seed but a lot of labor. Until recently, transplanting was mainly done by hand. With rising wages, mechanical rice transplanters have begun to take off. However, the prevalence of mechanized planting is still rather low compared to other steps of production because mechanical rice transplanters require specificity in seedling plantings in nurseries. The high coordination cost of synchronization between seedling nurseries and operators of rice transplanters is a major obstacle to the spread of transplanters.

Hypothesis 4: Migratory labor-cum-machine services are more applicable to machines with only a specific use than those with multi-functionality.

Let us use the trend of small and big tractors to illustrate this point. Figure 3.4 shows that the small tractor dominates the tractor stock of China. In 1978 there were only some 1 million small tractors (mainly power tillers) and the number rose to nearly 18 million by 2012. Figuring roughly with the datum (from government statistics) of 11 hp as the size of one small tractor in 1978, that means 11 million hp in 1978; with the datum of 13 hp per small tractor in 2012, that means 234 million hp in 2012: this is 21 times the hp stock of small tractors in 1978, a spectacular increase. These small tractors can be used to pull a number of attachments such as diskers, and also serve for other purposes such as transport. The multi-functionality of small tractors enables farmers to make use of them during slack seasons, reducing the pressure to expand the area of cultivation.

Figure 3.4 Number of small tractors versus big tractors



Source: Data come from *China Rural Statistical Yearbook* (NBS 2011).

In 1978 there were about 800 thousand large/medium tractors; at roughly 42 hp each (per government statistics), that implied a stock of 33.6 million in 1978 (three times the hp stock of small tractors). This number stayed low until 2005, when it began a rapid rise from 1 million large/medium tractors to near 5 million by 2012. The total horsepower of the 2012 stock, at 38 hp per large/medium tractor (per statistics), implies about 190 million hp (81 percent of the hp stock of the small tractors). There was thus a fivefold increase in the hp stock of medium/large tractors over the period—a substantial rise, although only a quarter as much as the rise of small tractors.

The rapidity of the 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, the relatively small investment a small tractor implies, and the tractor's multi-functionality. Less obvious is why there was a rise in the demand for large/medium tractors, in particular after 2004. Several reasons explain the latter.

First, large/medium tractors are used mainly to plow and pull large combines for rice and wheat harvesting. Plowing and harvesting are power-intensive activities that were formerly performed manually and have been increasingly handled with combines, which are driven by trucks and large tractors. This may be linked to the rise in rural wages that occurred around 2004 noted above (Zhang et al. 2011).

Second, however, the rise in wages 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 versus a large tractor for a small farmer. 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 of use for plowing and pulling a large combine harvester. Owning these large machines would not pay off for a small farmer, as the fixed cost relative to landholdings is very high, and the large machine also has limited multi-functionality. In summary, the burgeoning trend of large tractors in the past ten years suggests the likely emergence of migratory mechanization services for plowing and harvesting.

Hypothesis 5: Coordination is crucial for migratory labor-cum-machine services.

As shown in (4), variable cost α also affects the scale of migratory machination services. In addition to fuel and labor, coordination is costly. If going alone, a farmer will have to search for jobs, take care of repairing, and handle all problems himself. If going in a group, members can share the cost. However, traveling in groups involves coordination costs. Thus, it is crucial to figure a way to lower the coordination cost for traveling in a group. We discuss below in greater detail the inner workings of labor-cum-machine service cooperatives using an in-depth case study.

The demand side analysis shows that some power-intensive steps of agricultural production have been outsourced to specialized service providers. Of course, the adoption of mechanization varies by cost of machinery, seasonality, stage of production, and type of crops. In sum, division of labor is more widespread in agricultural production than previously presented in the literature.

4. THE EVOLUTION OF CROSS-REGIONAL MECHANIZATION SERVICES

In the section, we discuss a case study of a cluster of such labor-cum-machine harvesting services based in Peixian County, Jiangsu province, one of the first and largest cross-regional mechanization service clusters. Peixian is in the extreme north of Jiangsu province, bordering two other provinces (Shandong and Henan). The county is well connected to the national transportation network. Peixian is composed of 16 townships. There are 36 cross-regional mechanization service cooperatives in Peixian. The county seat alone has seven cooperatives. The mechanization service providers form their own cooperatives (separate from farm cooperatives per se). They mainly specialize in wheat and rice harvesting. Peixian has about 2,100 combine harvesters, and more than 1,000 of them are involved in cross-regional harvesting.

The idea of cross-regional services originated in 1997. Peixian Bureau of Agricultural Mechanization (PBAM) selected eight directors from 18 agricultural mechanization service stations dispersed in different townships in the county and organized a study tour to Weifang of Shandong province to learn about their mechanization experience. They also visited Henan, Anhui, Tianjin, and Hebei provinces to meet with the staff of local agricultural mechanization bureaus and farmers to explore the potentials of cross-regional harvesting services. After returning home from the tour, PBAM organized free demonstration and training sessions for farmers and technicians at the township agricultural mechanization service stations. After completing training, PBAM issued a certificate allowing the trainees to drive trucks and combines to provide harvesting services. In addition, PBAM gathered harvest information nationwide, printed a pocketsize harvest calendar covering major cropping areas, and distributed them to potential machinery operators for free.

In the first two years (1998 and 1999), PBAM helped form a harvest team composed of nearly 50 combines. Each combine had three or four operators. Led by a deputy director of PBAM, the group traveled to Zhumadian, of neighboring Henan province, to harvest wheat. At the time, the two major models of combines were Xinjiang No.2 and Futian. However, they were too heavy to be transported by truck, so they could be only driven slowly to nearby regions. Moreover, they were not reliable and often broke down. To cope with the repair and maintenance problems, the county invited a few technicians from the combine manufacturers to join the harvest team. The service expedition to Henan was a success. On average, a combine brought the owner a net profit of 60,000 yuan, much higher than farm incomes at the time. The word of cross-regional harvesting services as a profitable business model quickly spread. Following suit, more entrepreneurs purchased combines and entered the business.

As the business grew, it was impossible for PBAM to escort all the harvesting teams. By 2000, PBAM stopped escorting any teams. Instead, it facilitated operators to form their own small groups and selected experienced team leaders. On average, each group included 10 combines and about 40 operators. All the members in a team traveled together following the same route. Traveling in a group offers several advantages. The first advantage is security. When traveling far away from home, one often faces various unexpected challenges, such as extortions from gangs. By staying in groups, they faced a smaller chance of being extorted because a team of 40 or so strong young workers is a natural deterrent from potential harassment.

Second, traveling in a group can help teams cope with repair problems, one of the largest risks associated with long-distance cross-regional harvesting. It is cumbersome and expensive for an individual combine to bring all the commonly broken parts. When traveling in a group, although each person carries only a few parts, pooling them helps deal with most of the common problems. In rare cases when a group runs out of spare parts, they call other teams nearby for help. For some large teams with more than50 combines, they even bring their own service truck.

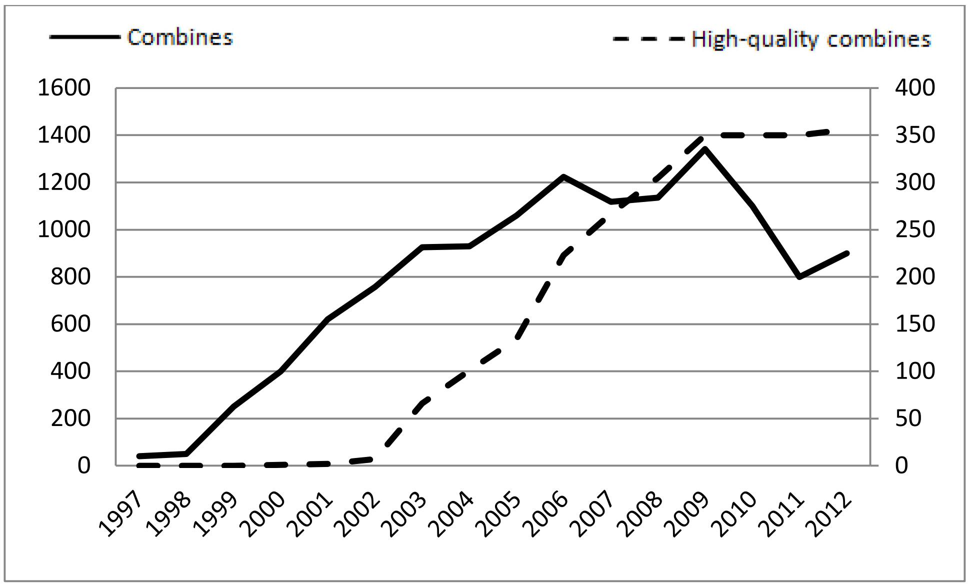
Third, traveling as a team lowers the search cost. It is common for a cooperative to hire a scout with a motorcycle to search for new harvesting orders, while operators focus on harvesting.7 Because all

[7] In some sense, this is very similar to honeybee scouts, who are specialized in looking for hives (Seeley 2010).

the team members share the scout cost, each individual bears only a small proportion of the total search cost.

Initially, because the combines pulled by tractors were too heavy to travel long distance, their radius of harvesting service was limited to only a few counties in Jiangsu province and neighboring Henan and Shandong provinces. Beginning in2003, a more reliable and smaller model, Kubota, made in Japan, gradually replaced the old model in the market. Because of its small size, a truck can carry it for long distances. The diffusion of small combines quickly revolutionized cross-regional harvesting services (see Figure 4.1).

Figure 4.1 The number of combines in Peixian over time



Source: Calculated by authors based on authors' survey (2013).

When traveling in a group, coordination among team members is a key challenge. In the first several years, cooperative leaders spent a lot of money on cell phone calls because changes in schedule, route, or meeting places had to be relayed to all the members one by one. They complained about the problem to the PBAM. In response, the PBAM worked with China Mobile, one of the largest telecommunication companies in China, to set up a group message service for the harvesting teams in 2011. As a result, the telecommunication cost dropped dramatically.

Most Chinese highways charge tolls. For long-distance travel, the toll cost can be prohibitive. Starting in 2004, the central government waived the tolls for all the trucks carrying combines or tractors that are engaged in cross-regional harvesting services (Ministry of Transport 2004).

As noted above for the country as a whole, the biggest driver for demand for mechanization was probably raising labor costs; that applies here to demand for outsourced mechanization services. Since 2003, real wages appreciation has escalated with a double-digit annual increase (Zhang et al. 2011). Rising wages induced farmers to substitute labors with machinery for the power-intensive production steps, such as plowing and harvesting.

On the supply side of machines for this service cluster, subsidies played a role. Beginning in 2004, the central government started to provide subsidies for farmers to purchase agricultural machinery (Bai 2004). The subsidy amount has increased over time. Farmers who purchase tractors with over 100 horsepower are entitled to a subsidy from the central government as high as 150,000 yuan, while the subsidy for a 200-hp tractor caps at 250,000 yuan (Ministry of Agriculture 2013). In addition, mechanization service cooperatives can apply for subsidies, which range from 30,000 to 100,000 yuan, to build warehouses for their machinery.

However, the subsidy may also exert a negative impact on cross-regional mechanization service providers. With a lower effective purchasing cost thanks to subsidy, owners of combines do not need to travel as far as before to recoup the machinery cost. When farmers in many other regions purchase their own combines under the support of subsidy, the Peixian service cluster faced greater numbers of competitors. This is perhaps why the total number of combines in Peixian has declined in the past several years, as shown in Figure 4.1.

In sum, both the rising labor cost and the active roles of local and central government, followed by intense local private investment by farmers, have contributed to the rapid development of the Peixian mechanization service cluster.

In 2011, we conducted qualitative interviews with combine operators, cooperative leaders, and local officials. Based on the qualitative interviews, we designed a questionnaire and first tested it in Anhui province.[8]After the test, we further revised the questionnaire. In March 2012, we formally launched our survey in Peixian. We randomly selected eight from 31 mechanization service cooperatives and interviewed the members of the chosen cooperatives. In total, we completed 124 interviews.

Table 4.1 reports the median income and cost among the interviewed cooperative members. On average, each member earned US$14, 286, which is seven times the per capita rural net income in Jiangsu province. Wages (US$7,937) account for 35 percent of the total cost. Fuel is the second most expensive item, constituting 28 percent of the total cost. Food and lodging consume 21 percent of total expenses. Repair and maintenance cost US$3,175, or 14 percent of total expenses. Telecommunication represents only 1.4 percent of the overall cost. Each combine harvests 133 hectares (ha) of land, serving more than 250 farmers, given that the average farm size in China is around 0.5 ha.

Table 4.1 Summary statistics of Combine Service Enterprise (CSE) survey in Peixian

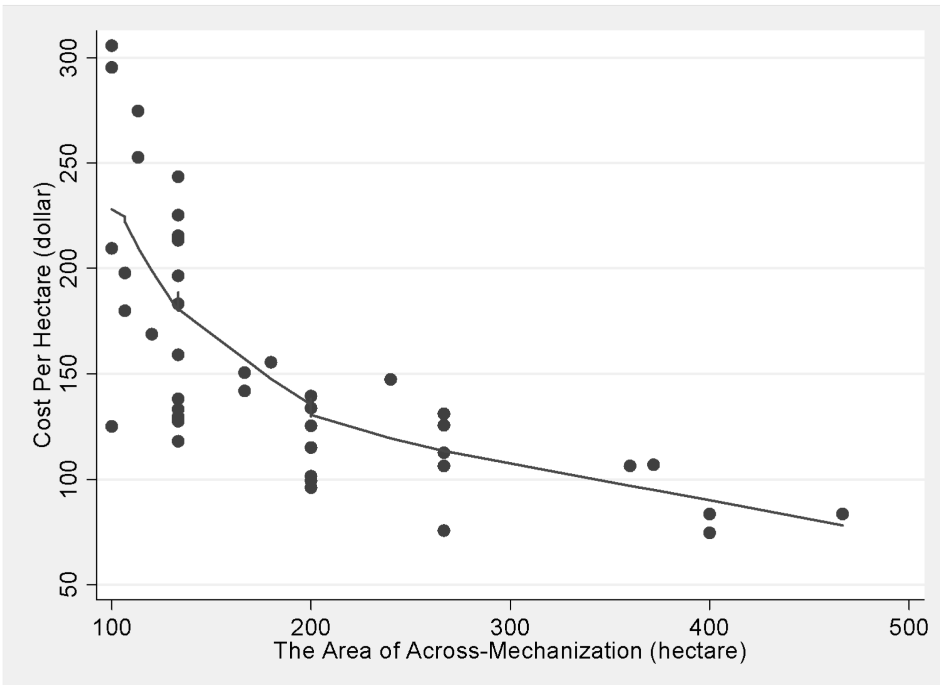
Variable	Median	observation
1. Net income ($)	14,285.71	103
2. Total costs ($)	22,539.68	
a) Repair and maintenance	3,174.60	102
b) Employee wages	7,936.51	87
c) Telephone	317.46	103
d) Food/lodging while traveling	4,761.90	65
e) Gasoline/diesel	6,349.21	89
3. Area served (hectares)	133.33	89
4.Days working away from home	179.00	107

Source: Calculated by authors based on authors' survey (2013).

[8] We did not test it in Peixian of Jiangsu province to avoid contaminating the sample.

Figure 4.2 plots the average cost per hectare versus total hectares of land harvested. As shown in the figure, the average cost per hectare comes down as the harvested area increases. This is consistent with the prediction of equation (4). Indeed, cross-regional harvesting exhibits increasing returns to scale. The longer time one harvests, the higher the net profit. In our sample, the operators travel on average 179 days (about six months) with some as long as eight months.

Figure 4.2 Cost per hectare and area harvested by Combine Service Enterprises



Source: Drawn by authors based on authors' Peixian Survey (2013).

5. CONCLUSIONS

Lack of production scale has been long regarded as a major constraint of smallholder farmers in the literature. In this paper, we show this conventional wisdom may not be true. Agricultural production can be divided into multiple steps. When the nonfarm job opportunities are limited and wages are low, farmers tend to undertake most steps of production by themselves. However, as real wages increase, it becomes cheaper for farmers to outsource some of the power-intensive steps to professional service providers, such as labor-cum-machine services, than to manually harvest crops. Because China is a large country with diversified production seasons, labor-cum-machine service providers can travel widely for a long period, greatly lowering their unit cost of operation and essentially substituting for the more expensive manual harvesting. This explains why despite the declining labor input in agricultural production, land productivity in China has not declined. The availability of the cheaper option of labor-cum-machine services is a key reason.

The emergence of the national labor-cum-machine service market may also help the nonfarm sector. When mechanization services are absent, migratory workers have to return home to help harvest crops, disrupting the normal production in the nonfarm sector. Now that the service is readily available for hire, migratory workers do not need to rush home during the peak seasons. This in turn may help boost labor productivity in the nonfarm sector; that is a hypothesis to test in future research.

By sourcing labor and power-intensive steps of production to others, smallholder farmers can maintain their competiveness despite their small and fragmented land size. However, as the current old-generation farmers with low opportunity cost of labor die out in the near future, land consolidation will become inevitable.

The Chinese experience highlights that agricultural production can be divisible in the same way as in industrial production. If we ignore the fine division of labor, we may draw a less precise assessment of the competiveness of Chinese agriculture and its potential. Paying greater attention to the structure of production can help us better understand the working economy (Coase and Wang 2011).

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