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Mechanization outsourcing clusters and division of labor in Chinese agriculture

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ABSTRACT

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 the 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 provide harvesting services at competitive prices. Through such an arrangement, smallholder farmers can stay viable in agricultural production.

1. Introduction

In the *Wealth of Nations* (Smith, 1776), Adam Smith emphasized the gains from specialization arising from two types of division of labor. The first type is division of labor within the firm, as famously illustrated in the example of 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. The second type refers to division of labor across producers as shown in the linen shirt example in Smith's book. The production of linen shirts was dispersed over many workshops. Smith posited that market size determines the division of labor. Due to a lack of scale, the division of labor in agricultural production is not as common as in industrial production.

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 the division of labor and mechanization—was manifest again in Asia from the 1950s to the present. Ruttan (2001) puts forward nearly the same ideas and terms as Smith and Marshall. He emphasizes that using machines for the series of short tasks on tiny farms would imply costly investment in specialized machinery that small

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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 hectares (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 0.5 ha—has both evolved a division of labor and experienced rapid farm mechanization. There is a paradox: despite rapid increase in real wages in the past decade, China has seen steadily climbing farm output and yields. 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. The increasing trend of outsourcing mechanization services primarily reflects the second type of division of labor as implied by Adam Smith. Although at the farm level the scale of production is small, certain stages of production, such as harvesting, can be undertaken at a much larger scale, allowing for a division of labor between farmers and mechanization service providers to take place.

This paper focuses on the second type of division of labor in Chinese agricultural production, in particular the emergence of a cluster of farmer cooperatives that sell outsourcing 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, Akinola (1987) documents how the operators of tractors traveled across regions to provide land preparation services in the 1970s and 1980s in Africa. Even in the US where farm size is much larger than many developing countries, migratory wheat harvesting service was present a century ago (serving farms that were smaller than those today and farmers who did not yet own their own machinery) (Olmstead & Rhode, 1995).[1]

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 outsourced. 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 sub-Sahara African countries 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 & Shand, 1986, and Jayasuriya, Te, & Herdt, 1986). After a mainly dormant period of some three decades, there has been a second wave of literature on mechanization (for example, Takahashi & 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. This paper extends Yang, Huang, Zhang, and Reardon (2013) by offering more detailed information about the inner workings of mechanization harvesting service clusters and developing a conceptual framework to understand the underlying mechanism.

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 0 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 0 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.

[1] See (https://uschi.com/index.php). Interestingly, farmers in the U.S. outsource not only mechanization services but also pollination services. Migratory beekeepers provide pollination services to commercial fruit and nut producers from one area to another (Chang, 1973; Muth, Ruckers, Thurman, & Chuang, 2003).

2.1. Farm labor drain

In 1978, more than 92% 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, Chenery, & Srinivasan, 1988) and partly due to the restriction of labor mobility by the household registration system implemented in the 1950s (Lin, Cai, & Li, 2008).

Although rural population density is still relatively high, and farms average about 0.5 ha (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 only 40% 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% of rural employment and 8% of rural income in 1978; by 1996 it accounted for 30% of rural employment and 34% 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.[2] 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% in 1970 to 0.48% in 2012. As a result, China's working-age labor force, including in rural areas, started to shrink in 2012.[3]

That shift of labor out of agriculture induced many media reports on labor shortages. It also contributed to wage increases: Zhang, Yang, and Wang (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.[4]

2.2. 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.

Despite the drop in farm labor and rising wages, rice yields in tons per ha went up from about 4 in 1978 to 6.8 in 2012; wheat yields increased by 178% from about 1.8 tons per ha in 1978 to 5 tons per ha in 2012; maize yields more than doubled from 2.8 tons to 5.0 tons in the same period (NBS, 2013).

The decrease in farming labor per se does not reduce agricultural output. Some early literature (Lewis, 1954; Pingali, 1997) contends that declining farm labor does not necessarily cause a fall in farm production in developing countries. In fact, Lewis (1954) argues that the farm (and nonfarm) sector in underdeveloped economies employ a large number of "messengers" whose contribution to production is almost negligible and hence marginal productivity of labor is negligible or even zero. When the supply of rural labor to the manufacturing sector is unlimited, the marginal productivity of labor in farming remains negligible.

However, when a country passes the so-called Lewis turning point, when surplus labor is exhausted, a drop in the farm labor force in principle would harm agricultural productivity. Since 2003/2004, real wages in China have grown by more than 10% per year, indicating that the era of Lewis-type surplus labor had come to an end (Zhang et al., 2011), decreasing labor input to farm fields during this stage should cause little harm to land productivity. Despite rapidly rising real wages since 2003/2004, agricultural productivity has grown at the same pace as in the period prior to the arrival of Lewis turning point. This is a puzzle.

2.3. The puzzle explained: the rapid rise of farm mechanization

Fig. 1 shows that from 1978 to 2012, farm machinery usage, proxied by kilowatts (kw) of energy expended by the machines, rose seven fold, from about 150 million kw in 1978 to more than 1 billion kw in 2012. In a rough calculation, noting that each unit of mechanical horsepower (hp) is equal to 0.75 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

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

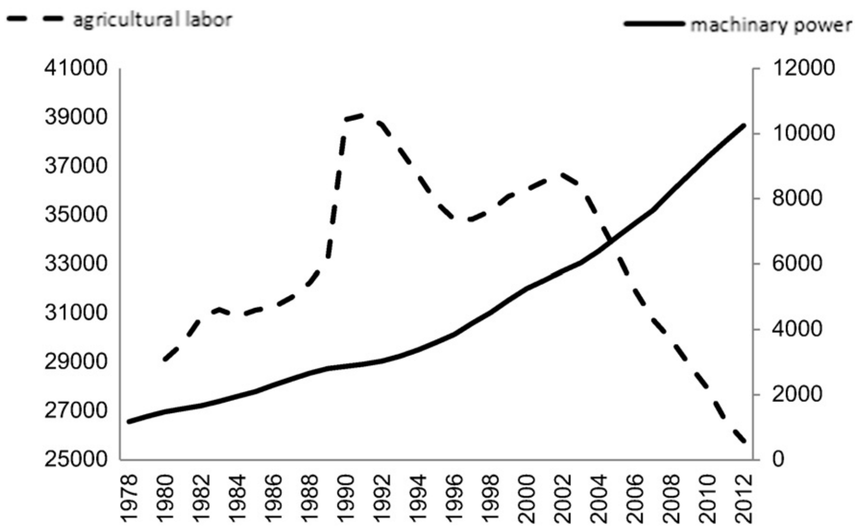

Fig. 1. Number of agricultural workers and machinery power Source: Data come from China Statistical Yearbook (NBS, 2011). Note: Unit of machinery power is 100,000 kw.

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.

We posit that mechanization services are provided by outside sourcing to farmers who do not own machinery. To test this hypothesis, we used data from the panel 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 not added to the questionnaire until 2004. In the empirical analysis, we use panel data from 2009 to 2012, covering 49,301 households.

When evaluating the effect of mechanization input on agricultural production, we also need to control for other input factors (Pingali, 1997), such as seed, fertilizer, and pesticide. Table 1 presents the summary statistics of both output and input variables

Table 1
Average agricultural production and input at the household level.

Variable	2009	2010	2011	2012	Annual growth rate
Panel A: Wheat					
Output (kilogram)	1145.23	1143.99	1128.89	1103.01	−1.24%
Land size (hectare)	0.22	0.22	0.21	0.21	−2.13%
Yield (kg/hectare)	5219.32	5264.38	5307.70	5362.97	0.91%
Labor input (days)	35.58	37.05	36.76	32.93	−2.55%
Seed fee ($)	18.84	20.00	21.21	21.60	4.67%
Fertilizer fee ($)	51.35	51.64	55.31	62.01	6.49%
Pesticide fee ($)	5.91	6.96	7.16	8.60	13.29%
Machinery fee ($)	34.88	36.04	36.87	45.35	9.14%
Panel B: Rice					
Output (kilogram)	1493.27	1403.35	1320.29	1344.74	−3.43%
Land size (hectare)	0.21	0.20	0.19	0.19	−3.35%
Yield (kg/hectare)	7248.35	7025.61	6835.60	7230.45	−0.08%
Labor input (days)	55.01	54.59	51.54	48.11	−4.37%
Seed fee ($)	12.82	13.89	15.95	17.42	10.75%
Fertilizer fee ($)	54.64	50.88	52.48	56.49	1.12%
Pesticide fee ($)	16.72	16.65	16.63	19.33	4.96%
Machinery fee ($)	25.86	26.88	30.75	37.59	13.28%
Panel C: Maize					
Output (kilogram)	1740.05	1786.08	1846.85	1953.74	3.94%
Land size (hectare)	0.25	0.26	0.26	0.26	0.34%
Yield (kg/hectare)	6849.50	6857.71	7137.54	7612.33	3.58%
Labor input (days)	45.60	45.78	45.17	42.49	−2.33%
Seed fee ($)	19.02	21.17	23.25	26.71	11.98%
Fertilizer fee ($)	58.13	58.76	64.75	75.12	8.92%
Pesticide fee ($)	6.61	7.52	7.96	9.20	11.67%
Machinery fee ($)	21.76	23.53	24.55	32.20	13.96%

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

used in the regressions. As shown in Panel A for wheat, both output and planting area have declined from 2009 to 2012 by 1.24% and 2.13% per year, respectively. Yield increased by 0.91% per year in the sample period.

The contraction of rice production is more pronounced than wheat. Total production per farm dropped by 3.43% per year, while rice acreage per farm declined by 3.35% per year. Rice yields witnessed a decline from 7.25 tons per ha in 2009 to 7.23 tons in 2012. By comparison, maize output, planting area, and yield have all experienced growth in the same period. The annual growth rate of maize yield was 3.94%.

In the same period, labor input actually declined from 36 days to 33 days in wheat, 55 to 48 days in rice, and 46 to 42 in maize production. The expenditure on machinery use jumped by 9.14%, 13.28%, and 13.96% per year for wheat, rice, and maize, respectively. Apart from machinery expenditures, other non-labor inputs (seed, fertilizer, and pesticide) have also grown rapidly, in particular pesticide cost for wheat and seed expenditure for rice and maize. It appears that the increasing expenditure on non-land inputs has offset the decline in labor use.

Using the RCRE panel dataset, we estimate the following Cobb-Douglas production function at the household level and quantify the contribution of various inputs to agricultural production:

$$y = \beta_0 + \beta_1 land + \beta_2 \text{labor} + \beta_3 seed + \beta_4 fertilizer + \beta_5 pesticide + \beta_6 machine + \beta_7 demogrphic + \varepsilon \quad (1)$$

Land is cropping area of grain; seed, fertilizer and pesticide inputs are measured in value terms constant in 2009 prices; machine refers to the machinery rental cost. These variables are all in nature logarithms. In addition, we include the household head's age and education to reflect household characteristics.

Table 2 presents the ordinary least square (OLS) estimation of production functions for three crops, wheat, rice, and maize. All the three regressions include province fixed effects, year fixed effects, and their interactions. The results are rather consistent across the three regressions. Land has the largest elasticity with respect to output, followed by fertilizer. For rice, machinery use has the third-largest elasticity, while for wheat and maize it ranks fourth in elasticity. The table also displays the *p*-value of *t*-test on constant returns to scale (the sum of the coefficients for all the inputs equal 1). The test does not reject the null hypothesis of constant returns to scale for all the three crops.

However, the OLS estimations may be subject to endogeneity problems. For instance, productive farmers may intentionally choose better seeds and hire more harvesting services to increase crop yields. To address the problem, we repeat Table 2 following the method of Levinsohn and Petrin (2003, shortened as LP method hereafter). In the context of the Chinese economy, Yu (2014) applies the LP method by using a firm's export status as a proxy for its unobserved productivity. In the field of agricultural economics, Brambilla and Porto (2005) employ the share of cotton cropping area to infer a farmer's cotton productivity when applying the LP method. Following the same spirit, here we use whether a farmer rents in land as a proxy for unobserved idiosyncratic crop productivity. A more productive farmer is more likely to rent in land than a less productive farmer. As shown in Table 3, the main findings based on LP estimations remain in force. Land still has the largest elasticity with respect to output. The coefficient for machinery use is positive and statistically significant in all the three regressions. Both the OLS and LP estimations indicate that mechanization plays an important role in determining wheat, rice, and maize production.

Table 2
The OLS estimation of production function for three crops.

Variable	Wheat	Rice	Maize
Land	0.467***	0.811***	0.426***
	(0.06)	(0.02)	(0.07)
Labor	0.04	(0.01)	0.04
	(0.02)	(0.02)	(0.02)
Seed	0.052**	0.006**	0.169***
	(0.02)	(0.00)	(0.04)
Fertilizer	0.331***	0.010***	0.312***
	(0.05)	(0.00)	(0.04)
Pesticide	0.060***	0.00	0.024**
	(0.01)	(0.00)	(0.01)
Machinery use	0.032***	0.008***	0.015***
	(0.01)	(0.00)	(0.01)
Age of household head	0.000**	0.00	0.00
	0.00	0.00	(0.00)
Education of household head	0.00	0.00	0.006**
	(0.00)	(0.00)	(0.00)
Test CRS (*p*-Value)	0.15	0.18	0.31
Year effect	Yes	Yes	Yes
Province effect	Yes	Yes	Yes
Province*year effect	Yes	Yes	Yes
N	14,622	11,802	25,539
Adjusted R^2	0.99	0.99	0.99

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

Table 3
The LP estimation of production function for three crops.

Variable	Wheat	Rice	Maize
Land	0.492***	0.811***	0.481***
	(0.02)	(0.01)	(0.02)
Labor	0.024***	−0.012*	0.025***
	(0.01)	(0.01)	(0.01)
Seed	0.051***	0.007***	0.148***
	(0.01)	(0.00)	(0.01)
Fertilizer	0.319***	0.010***	0.277***
	(0.02)	(0.00)	(0.01)
Pesticide	0.052***	0.00	0.025***
	(0.00)	(0.00)	(0.00)
Machinery use	0.034***	0.008***	0.014***
	(0.00)	(0.00)	(0.00)
Age of house head	0.001**	0.000*	0.000*
	0.00	0.00	0.00
Education of house head	0.002**	0.00	0.004***
	(0.00)	(0.00)	(0.00)
Year effect	Yes	Yes	Yes
Province effect	Yes	Yes	Yes
Province*year effect	Yes	Yes	Yes
N	14,622	11,802	25,539
Wald test CRS = 1(*p*-Value)	0.58	0.43	0.14

Source: Calculated by authors based on the RCRE household surveys (2009–2012).
Note: Dependent variable and independent variables are function of natural logarithm. The estimation method is based on Levinsohn and Petrin (2003). Robust standard errors are in parentheses. The symbols *, **, and ***represent levels of significance at 10%, 5%, and 1%, respectively.

3. Economics of cross-regional mechanization services

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

3.1. Supply side

For simplicity, we assume an average farm household operates one unit of land. The price of outsourcing mechanization services is P_m per unit of land. The purchase cost of machinery, say a combine harvester, is M. The depreciation rate of combine harvester is β. The variable cost of operation per unit of land (such as fuel, communication cost, meals and accommodation) is α.

If farmers sell the combine harvester on the γth year, the annualized fixed cost is:

$$\mathrm{m} = \frac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma} \tag{2}$$

If the combine harvester harvests n units of land, the total variable cost would be nα. Overall, the average cost per unit of land per year is:

$$c_s = {}^{(\mathrm{m}+\mathrm{n}\alpha)}\Big/_{\mathrm{n}} = \frac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma n} + \alpha \tag{3}$$

Only when the price of harvesting service P_m is higher than the cost c_s, is it profitable for one to own a combine harvester. The supply function of mechanization service can be written as:

$$\begin{cases} S = 1, & \text{if } \mathrm{P}_m \geq \dfrac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma n} + \alpha \\ S = 0, & \text{if } \mathrm{P}_m < \dfrac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma n} + \alpha \end{cases} \tag{4}$$

3.2. Demand side

Because of short window of time for harvesting, farmers often cannot harvest their own crop on time. In this situation, they face three choices:

1. Own a combine harvester

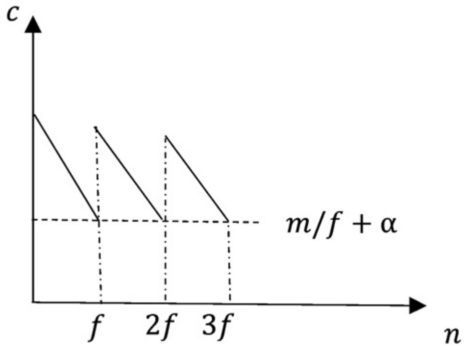

Fig. 2. Average cost of forming a cooperative Source: Drawn by authors.

If the operator of combine harvesting uses the combine only for his own harvesting, the total cost is $m+\alpha$. If he also provides harvesting services to other local farmers, provided that the maximum unit of land a combine can harvest in the limited local harvest season is f, then the total annual cost drops to: $m/f+\alpha$.If he can travel to other parts of China, the total harvest time would be much longer. Suppose he can harvest up to n units of land (much larger than f) by providing cross-regional harvesting services. The average cost will further decline to: $m/n+\alpha$.

2. Form a cooperative

On average a Chinese farm is too small to solely support a combine harvester. However, if they form a cooperative to increase farm size and share the cost of machinery purchase, the cost of operation drops. But due to the narrow window of local harvesting time, even if a combine runs at full capacity, it can only harvest f units of land. So the optimal farm size of a cooperative for owing a combine (without sourcing service out to other famers) is f (or $2f$ for owning two combines; or $3f$ for having three combines, and so on). Under the optimal farm size, the average cost is $m/f+\alpha$. Fig. 2 plots the average cost curve to own combine harvesters in relation to farm size. As shown in the figure, forming a cooperative does not bring about more cost advantage than owning a combine harvester and hiring extra services.

3. Purchasing services

If a farmer hires labor for harvesting, the cost is determined by market wages, w. If the farm is hiring mechanization harvesting services, the average cost per unit of land is $m/n+\alpha$. As discussed in point 1, the cost of hiring labor-cum-machine harvesting services is lower than that of forming a cooperative ($m/n+\alpha \ll m/f+a$). Thereby, farmers prefer hiring services to forming a mechanization cooperative. In the past decade, real wages have rapidly gone up, making it more cost effective for farmers to hire cross-regional mechanization harvesting services ($m/n+\alpha \ll w$) than to own a combine harvester.

When both the supply and demand conditions are fulfilled, the market for cross-regional mechanization services emerges:

$$\frac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma n}+\alpha \le P_m \le w \quad 5$$

Only when there are enough farms (m) to hire the service is there a possibility for the market to exist. The minimum number of farms is determined by:

$$\frac{M\left[1-(1-\beta)^{\gamma}\right]}{\gamma n}+\alpha = w \quad (6)$$

$$n_{min} = M\frac{\left[1-(1-\beta)^{\gamma}\right]}{\gamma(w-\alpha)} = m/(w-\alpha) \quad (7)$$

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.

First, the minimum feasible scale of mechanization services is positively correlated with the cost of machinery (m). 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 \$1000. As a result, those who own combines are more likely to travel to sell services farther over a longer period to recoup the cost than are those with plows. In 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 2008 and 2012.[5] Table 4 shows the prevalence of machinery use in land preparation, planting, and harvesting.

[5] 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). The final effective sample size is 1094.

Table 4
The use of machinery in Chinese agricultural production.

Year	Variable	Rice		Wheat		Maize	
		Using machinery	Hiring mechanization service	Using machinery	Hiring mechanization service	Using machinery	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). 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.

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% of farmers used machinery for plowing, while 74% of rice farmers used combine harvesters. 99% of the harvesting combines were used on a contract-hire basis. By comparison, among those who used mechanical plows, 82% 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 own-use, those who own plows also provide land preparation services to other farmers in their own or neighboring villages. Second, cross-regional migratory harvesting services are 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 over regions 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. From Eq. (7), only when n exceeds n_{min}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 large regional variation in seasonality probably is another reason behind the rapid diffusion of cross-regional harvesting service.

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. We plot the average cost curve of the two steps (Y_1 and Y_2) in Fig. 3. The horizontal axis is acreages harvested. The providers of harvesting services charge fees based on acreages harvested. Since the unit price per acre is largely fixed, the acreages harvested marked on the horizontal axis can be regarded as a proxy for total output of combine harvesters. 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 90%, higher than for maize (62%). Wheat harvesting relied heavily on combine harvesters (86%), most of which were labor-cum-machine services (98%). In comparison, the incidence of maize mechanized harvesting is only 28%. 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 standard 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.

4. The evolution of cross-regional mechanization services

In the section, we discuss a case study of a cluster of labor-cum-machine harvesting services based in Peixian County, Jiangsu province. This is 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 2100 combine harvesters, and more than 1000 of them are involved in cross-regional harvesting.

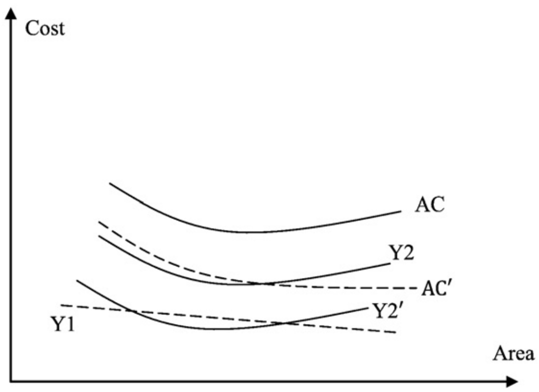

Fig. 3. The demand for mechanization services Source: Drawn by authors based on Stigler (1951).

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 potential 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 it to potential combine harvest 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 than 50 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.[6] Because all 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 services was limited to only a few counties in Jiangsu province and neighboring Henan and Shandong provinces. Beginning in 2003, a more reliable and smaller model, Kubota, made in Japan, gradually replaced the old models 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.

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.

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

Table 5
Summary statistics of combine service enterprise (CSE) survey in Peixian.

Variable	Median	Observations
1. Net income ($)	14,285.71	103
2. Total costs ($)	22,539.68	
a) Repair and maintenance	3174.60	102
b) Employee wages	7936.51	87
c) Telephone	317.46	103
d) Food/lodging while traveling	4761.90	65
e) Gasoline/diesel	6349.21	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).

When the migratory harvesting service providers travel to villages faraway, it is challenging for them to coordinate with farmers for synchronized harvesting. Intermediaries in villages play a key role in linking farmers and the operators of combine harvesters. The intermediaries are more knowledgeable about local demand than the service providers from outside. They normally charge 10% commission fee out of the total service charges. Operators rely heavily on intermediaries only when they first come to a village. However, after a few times of satisfactory services, their reliance on intermediaries weakens. It is more often than not they directly contact known farmers to schedule harvesting service.

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 behind the rising demand for mechanization outsourced mechanization services was probably the spike in 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 hp 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 Transport, 2004). 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 the 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.

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.[7] 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 5 reports the median income and cost among the interviewed cooperative members. On average, a combine harvest owner earned US$14, 286, which is seven times the per capita rural net income in Jiangsu province. Wages (US$7937) account for 35% of the total cost. Fuel is the second most expensive item, constituting 28% of the total cost. Food and lodging consume 21% of total expenses. Repair and maintenance cost US$3175, or 14% of total expenses. Telecommunication represents only 1.4% 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.

Fig. 4 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 Eq. (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.

5. Conclusions

Lack of production scale has been long regarded in the literature as a major constraint of smallholder farmers. 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

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

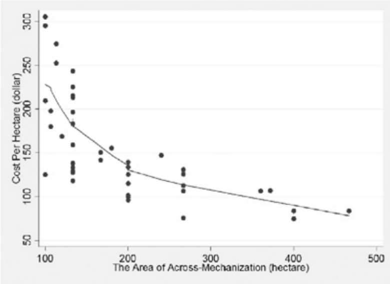

Fig. 4. Cost per hectare and area harvested by combine service enterprises (CSE) Source: Drawn by authors based on authors' Peixian Survey (2013).

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 is an important reason 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 and potentials of Chinese agriculture. Paying greater attention to the structure of production can help us better understand the working economy (Coase & Wang, 2011).

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