PART 2

Early-Adopter Asian Countries

Chapter 2

MECHANIZATION OUTSOURCING CLUSTERS AND DIVISION OF LABOR IN CHINESE AGRICULTURE

Xiaobo Zhang, Jin Yang, and Thomas Reardon

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 is difficult to explain the conundrum. When seeing agricultural production through 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.

Introduction

In *The Wealth of Nations*, Adam Smith ([1776] 1976) 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 10 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 10 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 is 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 echoed Smith's viewpoints in his *Principles of Economics*:

> In agriculture there is not much division of labor, and there is no production on a very large scale; for a so-called "large farm" does not employ a tenth part of the labor which is collected in a factory of moderate dimensions. (1920, 167)

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) put forward nearly the same ideas and terms as Smith and Marshall. He emphasized 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. Though recognizing the important role of mechanization in various steps of agricultural production, Pingali held 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. (2007, 2790)

Otsuka (2012) went 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-ha average to considerably more. Given that China's farm size is only one-third that of Japan, he warned that Chinese agriculture would likely repeat the path of Japan, relying heavily on subsidies and experiencing low growth in labor productivity.

Standing in contrast to the above prognosis for the Asian small farm sector to develop a division of labor and to mechanize, this chapter 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 for 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 "outsourcing" 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 defined 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 chapter 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 outsourced harvesting services (because harvesting is the most “heavy” of the tasks in agricultural production) across provinces for up to eight months a year. By participating in 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) documented how the operators of tractors traveled across regions to provide land preparation services in the 1970s and 1980s in Africa. Even in the United States, where farm size is much larger than in many developing countries, migratory wheat harvesting services were present a century ago, serving farms that were smaller than those in existence today and farmers who did not yet own their own machinery (Olmstead and Rhode 1995).[1]

This chapter makes two contributions. First, the chapter shows that for China, agricultural production can be as divisible as industrial production; this point has been largely neglected in the literature. When looking at production of small farmers through this lens, one can see that farm size becomes less of a limiting factor on scaling up production if some steps of production can be outsourced. Although our chapter 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 chapter 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; Jayasuriya, Te, and Herdt 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; Diao et al. 2012). An important motivation for the second wave of literature has been, as, for example, Takahashi and Otsuka (2009) noted, that a spur toward 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,

1 See, for example, US Custom Harvesters Inc., at uschi.com. Interestingly, farmers in the United States 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 et al. 2003).

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 two decades. This chapter extends Yang and colleagues (2013) by offering more detailed information about the inner workings of mechanization harvesting service clusters, and by developing a conceptual framework to understand the underlying mechanism.

The chapter proceeds as follows. The following section explores in greater detail the three trends noted above. The next section explains the economics of mechanized harvesting services, followed by a section that describes the supply of mechanized services based on a primary survey in Peixian county in Jiangsu province, China. The survey covers farmer cooperatives supplying migratory labor-cum-machine services to a number of provinces in China. A final section concludes.

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 than now (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 the country's rural population density is still relatively high, and farms average about 0.5 ha (one of the lowest sizes in the world), from 1978 to today, there has been a massive drop in the share of the population operating farms. In 2005, the Organization for Economic Co-Operation and Development estimated that only 40 percent of China's labor was in agriculture (McGregor 2005). This change 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) noted that from 1978 to 1997, the number of rural enterprises (owned by individuals and by the government) jumped from 1.5 million to 20.2 million. Moreover, rural industry was less than 10 percent of rural employment and 8 percent of rural income in 1978, but by 1996 it accounted for 30 percent of rural employment and 34 percent of rural income (Lin and Yao 2001). (Note that these figures underestimate rural nonfarm employment because in addition to rural manufacturing there is also substantial rural service-sector activity.)

Second, as China's cities grew and manufacturing 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. Besides 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 percent in 1970 to 0.48 percent in 2012. As a result, China's working-age labor force, including workers 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) reported that real wages had started to accelerate in 2003/2004, suggesting that the era of Lewis-type surplus labor had come to an end.[4]

Farm Output Growth

The above narrative chronicles a massive loss of rural people working on farms, in both the coastal and the interior provinces. This was not much

2 Deininger and Jin (2009) noted, however, that these rental limitations were gradually reduced in the 2000s.

3 See https://www.economist.com/free-exchange/2012/01/23/one-billion-workers.

4 For the original idea, see Lewis (1954).

compensated by rural population increase. Moreover, most of those who left farming were younger workers, the most physically productive.

Despite the fall in farm labor and rise in wages, rice yields in tons[5] per hectare went up from about 4 in 1978 to 6.8 in 2012; wheat yields increased by 178 percent, from about 1.8 tons per hectare in 1978 to 5.0 tons per hectare in 2012; and maize yields more than doubled, from 2.8 tons to 6.0 tons per hectare (NBS 2013).

The decrease in farming labor per se does not lower agricultural output. Some early literature (Lewis 1954; Pingali 2007) contended that declining farm labor does not necessarily cause a fall in farm production in developing countries. In fact, Lewis (1954) argued that the farm (and nonfarm) sector in underdeveloped economies employs a large number of "messengers," whose contribution to production is almost negligible and hence the marginal productivity of their labor is negligible. When the supply of rural labor to the manufacturing sector is unlimited, the marginal productivity of labor in farming remains negligible.

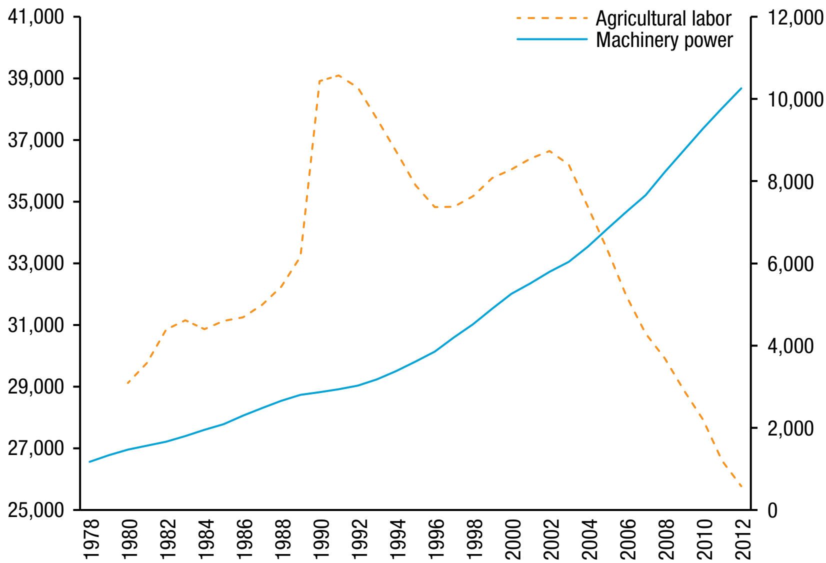
However, when a country passes the so-called Lewis turning point, when surplus labor is exhausted, a drop in the farm labor force would in principle harm agricultural productivity. Since 2003/2004, real wages in China have grown by more than 10 percent per year, indicating that the era of Lewis-type surplus labor has come to an end (Zhang, Yang, and Wang 2011), meaning that 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 at the Lewis turning point. In principle, rising labor cost would have significantly increased the cost of agricultural production, dragging down its growth. This is a puzzle.

The Puzzle Explained: The Rapid Rise of Farm Mechanization

Figure 2.1 shows that from 1978 to 2012, farm machinery usage, proxied by kilowatts of energy expended by the machines, rose sevenfold, 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 is equal to 0.75 kW, 1 billion kW comes to about 750 million hp of farm machinery. A smallish 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

5 "Tons" refers to metric tons throughout the chapter.

FIGURE 2.1 **Number of agricultural workers and amount of machinery power, China, 1978–2012**



Source: Authors, based on data from *China Statistical Yearbook* (NBS 2011).
Note: Unit of machinery power is 100,000 kW. Number of workers (left axis) is in 10,000.

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, Yang, and Wang 2011). This suggests that rural households were facing farm-level labor constraints in the agricultural peak seasons before the arrival at the Lewis turning point.

We posit that mechanization services are provided by outside sources to farmers who do not own machinery. To test this hypothesis, we use 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 2007), such as seed, fertilizer, and pesticide. Table 2.1 presents the summary statistics of both output and input variables used in the regressions. As shown in Panel A for wheat, both output and planting area declined from 2009 to 2012, by 1.24 percent and 2.13 percent per year, respectively. Yield increased by 0.91 percent per year in the sample period.

The contraction of rice production was more pronounced than that of wheat. Total production per farm dropped by 3.43 percent per year, whereas rice acreage per farm declined by 3.35 percent per year. Rice yields witnessed a decline from 7.25 tons per hectare in 2009 to 7.23 tons in 2012. In comparison, maize output, planting area, and yield all experienced growth in the same period. The annual growth rate of maize yield was 3.94 percent. This is likely associated with the demand shift as per capita consumption of wheat and rice declined, whereas meat consumption, which drives up demand for maize, increased.

In the same period, labor input actually declined from 36 days to 33 days in wheat, from 55 to 48 days in rice, and from 46 to 42 days in maize production. The expenditure on machinery use jumped by 9.14 percent, 13.28 percent, and 13.96 percent per year for wheat, rice, and maize, respectively. Apart from machinery expenditures, other nonlabor 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 nonland 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:

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

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

Table 2.2 presents the ordinary least squares (OLS) estimation of production functions for three crops, wheat, rice, and maize. All 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

TABLE 2.1 Average agricultural production and input at the household level, China, 2009–2012

Variable	2009	2010	2011	2012	Annual growth rate
Panel A: Wheat					
Output (kg)	1,145.23	1,143.99	1,128.89	1,103.01	–1.24%
Land size (ha)	0.22	0.22	0.21	0.21	–2.13%
Yield (kg/ha)	5,219.32	5,264.38	5,307.70	5,362.97	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 (kg)	1,493.27	1,403.35	1,320.29	1,344.74	–3.43%
Land size (ha)	0.21	0.20	0.19	0.19	–3.35%
Yield (kg/ha)	7,248.35	7,025.61	6,835.60	7,230.45	–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 (kg)	1,740.05	1,786.08	1,846.85	1,953.74	3.94%
Land size (ha)	0.25	0.26	0.26	0.26	0.34%
Yield (kg/ha)	6,849.50	6,857.71	7,137.54	7,612.33	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 China Ministry of Agriculture Research Center for the Rural Economy household surveys (2009–2012).

Note: Monetary values are in constant 2009 US dollars.

elasticity. The table also displays the *p*-value of a *t*-test on constant returns to scale (the sum of the coefficients for all the inputs equals one). The test does not reject the null hypothesis of constant returns to scale for all three crops.

However, the OLS estimations may be subject to endogeneity problems. For instance, productive farmers may intentionally choose better seeds and

TABLE 2.2 Ordinary least squares estimation of production function for three crops, China, 2009–2012

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 China Ministry of Agriculture Research Center for the Rural Economy 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 percent, 5 percent, and 1 percent, respectively. CRS = constant returns to scale.

hire more harvesting services to increase crop yields. To address the problem, we repeat Table 2.2 following the method of Levinsohn and Petrin (2003), shortened as "LP method" hereafter. In the context of the Chinese economy, Yu (2014) applied 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) employed 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

TABLE 2.3 Estimation of production function for three crops using Levinsohn and Petrin method, China, 2009–2012

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 household head	0.001**	0.000*	0.000*
	0.00	0.00	0.00
Education of household 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 China Ministry of Agriculture Research Center for the Rural Economy household surveys (2009–2012).

Note: Dependent variable and independent variables are functions 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 percent, 5 percent, and 1 percent, respectively.

a proxy for unobserved idiosyncratic crop productivity. A more productive farmer is more likely to rent in land than is a less productive farmer. As shown in Table 2.3, the main findings from the earlier OLS estimations remain in force under the LP estimations. Land still has the largest elasticity with respect to output. The coefficient for machinery use is positive and statistically significant in all three regressions. Both the OLS and LP estimations indicate that mechanization plays an important role in determining wheat, rice, and maize production.

Economics of Cross-Regional Mechanization Services

In the previous two sections, we have documented the rapid rise of farm mechanization and its impact on the growth of agricultural production. Interestingly, the increase in farm mechanization is through provision of cross-regional mechanization services rather than more widespread ownership of agricultural machinery. In this section, we analyze the economic mechanisms behind the flourishing cross-regional mechanization services from both the supply and the demand side.

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 a combine harvester is β. The variable cost of operation per unit of land (such as fuel, communication cost, meals, and accommodation) is α.

If the farmer sells the combine harvester in the γth year, the annualized fixed cost is

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

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

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

Only when the price of the 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 the mechanization service can be written as

$$\begin{cases} S = 1, if P_m \geq \frac{M[1-(1-\beta)^{\gamma}]}{\gamma n} + \alpha \\ S = 0, if P_m < \frac{M[1-(1-\beta)^{\gamma}]}{\gamma n} + \alpha. \end{cases} \tag{4}$$

Demand Side

Because of the 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.*

   If the operator of a combine harvester 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 farmers form a cooperative to increase the de facto 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 owning a combine (without sourcing service out to other famers) is *f* (or 2*f* for owning two combines, or 3*f* for having three combines, and so on). Under the optimal farm size, the average cost is $m / f + \alpha$. Figure 2.2 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 as an individual and hiring out services.

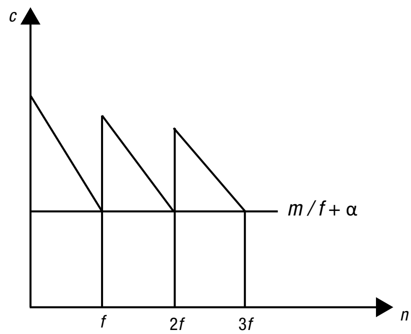
3. *Purchase services.*

   If a farmer hires labor for harvesting, the cost is determined by market wages, *w*. If the farm is hiring mechanized harvesting services, the average cost per unit of land is $m / n + \alpha$. As discussed in choice 1, the cost of hiring labor-cum-machine harvesting services is lower than that of forming a cooperative ($m / n + \alpha << m / f + a$). Therefore, farmers prefer hiring in these 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 in cross-regional mechanized harvesting services ($m / n + \alpha << \mathrm{w}$) than to own a combine harvester.

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

$$\frac{M[1-(1-\beta)^{\gamma}]}{\gamma n} + \alpha \leq Pm \leq w. \tag{5}$$

FIGURE 2.2 Average cost of cooperative ownership of combine harvesters



Source: Drawn by authors.

Note: α = variable cost of operation per unit of land; c = cost; f = maximum units of land a combine can harvest in the limited local harvest season; m = annualized fixed cost of owning a combine harvester; n = units of land a combine can harvest by providing cross-regional services.

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

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

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

This is the minimum feasible scale over which to spread the cost of machinery, as suggested by Jayasuriya, Te, and Herdt (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.[6] In comparison, a plow is normally less than $1,000. As a result, those who own combines are more likely to travel farther over a longer period to sell services 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.[7] Table 2.4 shows the prevalence of machinery use in land preparation, planting,

6 Dollar figures are US dollars throughout the chapter.

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

TABLE 2.4 Use of machinery in Chinese agricultural production, percentages, 2008 and 2012

		Rice		Wheat		Maize	
Year	Operation	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: Data from a complementary module of China Ministry of Agriculture Research Center for the Rural Economy 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 farmers hiring mechanization among those who used machinery.

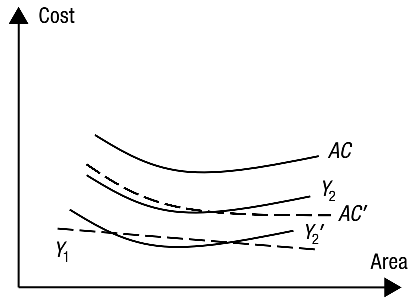
and harvesting. If a farmer used machinery, we further asked whether the machinery was on a contract-hire basis. Take rice as an example. In 2012, 86 percent of rice farmers used machinery for plowing, with 74 percent using combine harvesters. Of the harvesting combines, 99 percent were used on a contract-hire basis. In comparison, among those who used mechanical plows, 82 percent rented in the service, a rate lower than the hire-in rate of harvesting services. 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. Although it is possible for a large to medium tractor/combine to provide harvesting services in the local area, it may be difficult for its owner to find the needed number of clients in the local catchment area in such a short harvesting window. 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, yet 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 equation (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 services used to realize that division. The large regional variation in seasonality probably is another reason behind the rapid diffusion of cross-regional harvesting services.

The phenomena demonstrated above are 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, nonharvesting and harvesting. We plot the average cost curves of the two steps (Y_1 and Y_2, respectively) in Figure 2.3. The horizontal axis is acreage harvested. The providers of harvesting services charge fees based on acreage harvested. Because the unit price per acre is largely fixed, the acreages harvested marked on the horizontal axis can be regarded as a proxy for the total output of combine harvesters. If a farmer finishes both steps with own labor and machinery, 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 lower than 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 with 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 percent, higher than for maize (62 percent). Wheat harvesting relied heavily on combine harvesters (86 percent), most of which were labor-cum-machine services (98 percent). In comparison, the incidence of maize mechanized harvesting was only 28 percent. The popular models of maize combine harvesters in the United States, where there are 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.

FIGURE 2.3 Demand for mechanization services



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

Note: AC = beginning cost curve; AC' = cost curve with cheaper, hired-in harvesting service; Y_1 = cost of nonharvesting step; Y_2 = cost of doing own harvesting step; Y_2' = cost of cheaper, hired-in harvesting service.

The Evolution of Cross-Regional Mechanization Services

In this 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 7 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. The 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, a city in Shandong province, to learn about the mechanization experience there. The directors also visited Anhui, Henan, Hebei, and Tianjin provinces to meet with the staff of local agricultural mechanization bureaus and farmers to explore the potential of cross-regional harvesting services. After the directors returned 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, trainees were issued a PBAM certificate allowing them to drive trucks and combines to provide harvesting services. In addition, PBAM gathered harvest information nationwide, printed a pocket-size 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, a city in 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 $8,571, much higher than farm annual 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 the year 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 extortion from gangs. By staying in groups, they faced a smaller chance of facing extortion because a team of 40 or so strong, young workers is a natural deterrent to 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, it can call other teams nearby for help. Some large teams with more than 50 combines 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.[8] 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 distances, 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 PBAM. In response, 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.

When the migratory harvesting service providers travel to villages far away, 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 a 10 percent 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 providing satisfactory services, their reliance on intermediaries weakens. 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 outsourced mechanization services was probably the spike in labor costs; that also applies here. From 2003 to 2011, the appreciation of real wages escalated, with a double-digit annual increase (Zhang, Yang,

8 In a sense, this is very similar to honeybee scouts, who are specialized in looking for suitable sites for new hives (Seeley 2010).

and Wang 2011). Rising wages induced farmers to substitute machinery for laborers to do 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 greater than 100 hp are entitled to a subsidy from the central government as high as $21,428, whereas the subsidy for a 200 hp tractor caps at $35,714 (Ministry of Agriculture 2013). In addition, mechanization service cooperatives can apply for subsidies, which range from $4,285 to $14,285, 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 purchased 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.[9] After the test, we further revised the questionnaire. In March 2012, we formally launched our survey in Peixian. We randomly selected 8 from 31 mechanization service cooperatives and interviewed the members of the chosen cooperatives. In total, we completed 124 interviews.

Table 2.5 reports the median income and cost among the interviewed cooperative members. On average, a combine harvest owner earned $14,286 per year, which is seven times the per capita rural net annual income in Jiangsu province. Wages ($7,937) accounted for 35 percent of the total cost. Fuel was the second-most-expensive item, constituting 28 percent of the total cost. Food and lodging consumed 21 percent of total expenses. Repair and maintenance cost $3,175, or 14 percent of total expenses. Telecommunication

9 We did not test it in Peixian county of Jiangsu province to avoid contaminating the sample.

TABLE 2.5 Summary statistics of combine service enterprise survey in Peixian county, China, 2013

Variable	Median	Observations
1. Net income ($)	14,285.71	103
2. Total costs ($)	22,539.68	n.a.
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 (ha)	133.33	89
4. Days working away from home	179.00	107

Source: Calculated by authors based on authors' survey (2013).
Note: Monetary values are in US dollars. n.a. = not applicable.

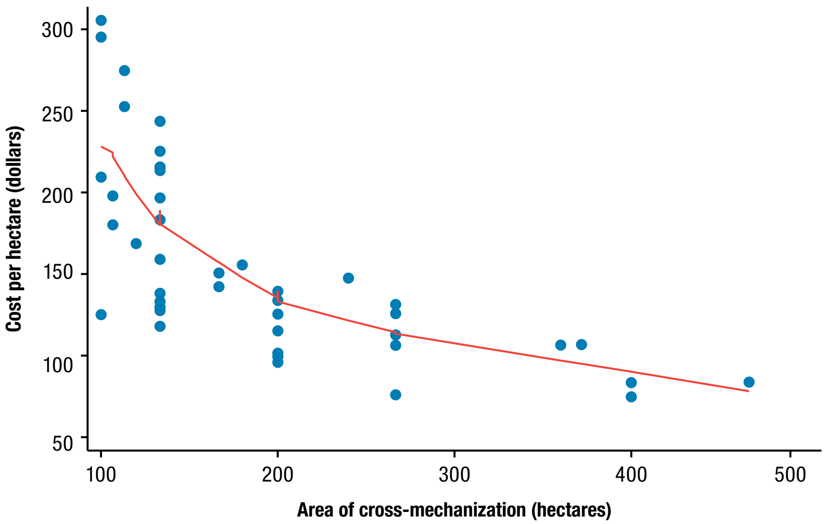
represented only 1.4 percent of the overall cost. Each combine harvested 133 ha of land, serving more than 250 farmers, given that the average farm size in China is around 0.5 ha.

Figure 2.4 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 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.

Conclusions

Lack of production scale has been long regarded in the literature as a major constraint on smallholder farmers. In this chapter, 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 service providers, 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

FIGURE 2.4 Cost per hectare and area harvested by combine service enterprises, Peixian county, China, 2013



Source: Drawn by authors based on authors' Peixian survey (2013).
Note: Dollars are US dollars.

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 outsourcing the labor- and power-intensive steps of production to others, smallholder farmers can maintain their competitiveness 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 industrial production. If we ignore the fine division of labor, we may draw a less precise assessment of the competitiveness and potentials of Chinese agriculture. Paying greater attention to the structure of production can help us better understand the working economy (Coase and Wang 2011).

As for policy recommendations, China's experiences offer important lessons for mechanization promotion in African countries. Although the agricultural and economic conditions of China differ from those of many African countries, China's recent experiences demonstrate good practices in many aspects that offer useful principles African countries can follow.

First, China's experiences demonstrate that constraints due to small farm size, combined with land fragmentation, can still be overcome, and mechanization can spread in such an environment if the right conditions (technological, institutional, and political) hold. Second, subsidies introduced in 2004 have been successful partly because they were less selective and thus less distorting than some subsidies in Africa. Although different caps were placed on tractors with different horsepower, no particular brands were favored, unlike the recent subsidies implemented in many African countries.

Third, as is described in the case study of a cluster of labor-cum-machine harvesting services based in Peixian county, Jiangsu province, the governments at various administrative layers played important coordinating roles, which is one of the key public goods. These coordination roles included linking service providers and customers, providing free harvest information, linking with providers of other services (mobile companies), and waiving of highway tolls, among others. These coordinating roles were complemented by investments in road infrastructure as well as irrigation infrastructure, which facilitated the expansion of production seasons where climatically feasible, lengthening the windows of harvesting seasons during which migratory harvesting services could recoup machine investment costs. If African countries were to develop similar migratory mechanization services, it would be critical that governments play similar coordinating roles and provide key infrastructures.

References

Akinola, A. 1987. "Government Tractor Hire Service Scheme as a Tractorization Policy in Africa: The Nigerian Experience." *Agricultural Administration and Extension* 25 (2): 63–77.

Bai, R. 2004. *Research on the Policy of Subsidy for Purchasing Agricultural Machinery*. Beijing: China Agricultural Science and Technology Press.

Binswanger, H. 1986. "Agricultural Mechanization: A Comparative Historical Perspective." *World Bank Economic Observer* 1: 27–56.

Brambilla, I., and G. G. Porto. 2005. *Farm Productivity and Market Structure: Evidence from Cotton Reforms in Zambia.* Economic Growth Center Discussion Paper No. 919. New Haven, CT, US: Yale University.

Chang, S. N. S. 1973. "The Fable of Bees: An Economics Investigation." *Journal of Law and Economics* 16 (1): 11–33.

Coase, R. H., and N. Wang. 2011. "The Industrial Structure of Production: A Research Agenda for Innovation in an Entrepreneurial Economy." *Entrepreneurship Research Journal* 1: 1–13.

Collier, P., and S. Dercon. 2013. "African Agriculture in 50 Years: Smallholders in a Rapidly Changing World?" *World Development* 63: 92–101.

Deininger, K., and S. Jin. 2009. "Securing Property Rights in Transition: Lessons from Implementation of China's Rural Land Contracting Law." *Journal of Economic Behavior and Organization* 70: 22–38.

Diao, X., F. Cossar, N. Houssou, S. Kolavalli, K. Jimah, and P. Aboagye. 2012. "Mechanization in Ghana: Searching for Sustainable Service Supply Models." IFPRI Discussion Paper 1237. Washington, DC: International Food Policy Research Institute.

Fan, C. 2009. "Flexible Work, Flexible Household: Labor Migration and Rural Families in China." In *Work and Organizations in China after Thirty Years of Transition,* edited by Lisa Keister, 377–408. Research in the Sociology of Work, Vol. 19. Bingley, UK: Emerald Group Publishing Limited.

Green, S. 2008. *On the World's Factory Floor: How China's Workers Are Changing China and the Global Economy*. Special Analysis of Key Topics. London: Standard Chartered Bank.

Jayasuriya, S., and R. Shand. 1986. "Technical Change and Labor Absorption in Asian Agriculture: Some Emerging Trends." *World Development* 14: 415–428.

Jayasuriya, S., A. Te, and R. Herdt. 1986. "Mechanization and Cropping Intensification: Economics of Machinery Use in Low-Wage Economies." *Journal of Development Studies* 22: 327–335.

Levinsohn, J., and A. Petrin. 2003. "Estimating Production Functions Using Inputs to Control for Unobservables." *Review of Economic Studies* 70 (2): 317–342.

Lewis, W. A. 1954. "Economic Development with Unlimited Supplies of Labor." *The Manchester School* 22 (2): 139–191.

Lin, Y., F. Cai, and Z. Li. 2008. *The China Miracle: Development Strategy and Economic Reform*, 3rd ed. Hong Kong: Chinese University of Hong Kong Press.

Lin, Y., and Y. Yao. 2001. "Chinese Rural Industrialization in the Context of the East Asian Miracle." In *Rethinking the East Asian Miracle*, edited by J. E. Stiglitz and S. Yusuf, 143–196. Washington, DC: The World Bank.

Marshall, A. 1920. *Principles of Economics*, 8th ed. London: Macmillan.

McGregor, R. 2005. "China Must Cut Farming Population, Says OECD." *Financial Times*, November 15.

Ministry of Agriculture of the People's Republic of China. 2013. *Guidance of the Policy of Subsidy for Purchasing Agricultural Machinery*. Beijing. http://jiuban.moa.gov.cn/zwllm/zwdt/201301/t20130125_3208634.htm.

Ministry of Transport of the People's Republic of China. 2004. *Regulation on the Administration of Toll Roads*. Beijing. http://www.gov.cn/zwgk/2005-05/23/content_241.htm.

Muth, M. K., R. R. Ruckers, W. N. Thurman, and C. T. Chuang. 2003. "The Fable of Bees Revisited: Causes and Consequences of the US Honey Program." *Journal of Law and Economics* 46 (2): 479–516.

NBS (National Bureau of Statistics of the People's Republic of China). 2011. *China Rural Statistical Yearbook*. Beijing: China Statistics Press.

———. 2013. *China Rural Statistical Yearbook*. Beijing: China Statistics Press.

Olmstead, A. L., and P. W. Rhode. 1995. "Beyond the Threshold: An Analysis of the Characteristics and Behavior of Early Reaper Adopters." *The Journal of Economic History* 55 (1): 27–57.

Otsuka, K. 2012. "Food Insecurity, Income Inequality, and the Changing Comparative Advantage in World Agriculture." Presidential address at the 27th International Conference of Agricultural Economists, Foz do Iguaçu, Brazil, August 18–24.

Pingali, P. 2007. "Agricultural Mechanization: Adoption Patterns and Economic Impact." In *Handbook of Agricultural Economics.* Vol. 3, edited by R. Evenson and P. Pingali, 2779–2805. Amsterdam: Elsevier.

Ruttan, V. W. 2001. *Technology, Growth and Development: An Induced Innovation Perspective*. New York: Oxford University Press.

Seeley, T. D. 2010. *Honeybee Democracy*. Princeton, NJ, US: Princeton University Press.

Smith, A. (1776) 1976. *The Wealth of Nations*. New York: Oxford University Press.

Stigler, G. J. 1951. "The Division of Labor Is Limited by the Extent of the Market." *Journal of Political Economy* 59: 185–193.

Takahashi, K., and K. Otsuka. 2009. "The Increasing Importance of Nonfarm Income and the Changing Use of Labor and Capital in Rice Farming: The Case of Central Luzon, 1979–2003." *Agricultural Economics* 40: 231–242.

Timmer, C. P. 1988. "The Agricultural Transformation." In *Handbook of Development Economics*. Vol. 1, edited by H. Chenery and T. N. Srinivasan, 275–331. Amsterdam: North-Holland.

Yang, J., Z. Huang, X. Zhang, and T. Reardon. 2013. "The Rapid Rise of Cross-Regional Agricultural Mechanization Services in China." *American Journal of Agricultural Economics* 95 (5): 1245–1251.

Yu, M. 2014. "Processing Trade, Tariff Reductions and Firm Productivity: Evidence from Chinese Firms." *Economic Journal* 125: 943–988.

Zhang, X., J. Yang, and S. Wang. 2011. "China Has Reached the Lewis Turning Point." *China Economic Review* 22: 542–554.