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Estimating the Effect of Land Fragmentation on Machinery Use and Crop Production

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Abstract:

Using a recent data set from farm households in the provinces of Hebei and Shandong, we investigate the effect of land fragmentation on machinery use as well as the effect of machinery use on crop production. Endogeneity is addressed by utilizing land fragmentation due to previous long-term land assignment as an instrument and first difference estimation between normalized wheat and corn output from the same plots in the same year. The main results indicate that consolidating an average farm of 0.31 hectares from 2.28 plots to one plot increases machinery use by about 10%. Further, a 10% increase of machinery use increases crop production between 0.5% and 1%.

Key words: agricultural production, China, land fragmentation, land use policy, machinery use

1. Introduction

Agricultural productivity is crucial to China's internal economic development and to global agricultural trade patterns in commodities and agricultural inputs. The land, labor and technology available to Chinese farmers fundamentally influence agricultural productivity. In terms of land, Chinese reforms of the past few decades have created fragmented agricultural land holdings resulting in many individual farmers tending to several small fields, often in distinct locations. In terms of labor, macroeconomic conditions and manufacturing sector dynamics have altered rural labor markets fundamentally such that a once plentiful supply of farm labor is now more limited. In terms of technology, agricultural machinery, which may logically substitute for increasingly scarce labor, has been the focus of recent government subsidies. Given that policy pathways exist in China to alter both machinery subsidies and patterns of land holdings, it is critical to understand the interactions between land fragmentation, farm machinery use and farm productivity. Less land fragmentation may be a crucial step to promoting the general productivity enhancing features of economies of scale, particularly the adoption of agricultural machinery in lieu of tightening farm labor availability. The promise of achieving economies of scale via land consolidation is also a likely reason why the Chinese government has recently moved to speed up the establishment of rural land markets where land usage rights can be subcontracted, leased, exchanged and pledged (No.1 Central Document,[1] 2014 and 2015; The Economist, 2014).

Extant research confirms that land fragmentation leads to lower productivity and higher

[1] This policy document is issued by the Central Committee of the Communist Party of China and the State Council every year and it has been dubbed the "No. 1 Central Document". These documents were issued early in 2014 and 2015, underscoring the importance of rural reforms, developing modern agriculture and maintaining agriculture as the foundation of the national economy. The documents promote to maintain the stability of rural land contract, strictly protect arable farmlands, and give farmers right to subcontract, lease, exchange and pledge their land.

cost (Blarel et al., 1992; Rahman and Rahman 2009; Tan et al. 2008; Tan et al. 2010; Van Hung, MacAulay, and Marsh 2007; Wu, Liu, and Davis 2005). Few studies have directly investigated the relationship between land fragmentation and investment in farm machinery. Several studies have found that farmers with more land will invest more in machinery to exploit economies of scale, and that larger plots are associated with higher profits per acre (Foster and Rosenzweig, 2010 and 2011). Mechanization on the smallest farms requires costly investment in specialized machines that small farmers may be loath to make (Otsuka 2013; Ruttan 2000). Following this logic, it would appear that farmers in China would invest little in machinery because the full efficiencies of mechanization are not available on such a fragmented agricultural landscape.

However, farm mechanization in China has increased steadily since 2004 because of the rapid rise of cross-regional agricultural mechanization services. Tractor and combine services are available for hire in many key provinces and take advantage of harvests that occur at different times across provinces (Yang et al. 2013). Farmers in China, therefore, can either use their own machinery or hire machinery services. From this point of view, previous research on farm size, machinery investment and farm production is not sufficient to describe the situation in China as most studies focus on machinery ownership (Liu and Tian 2009; Tan et al. 2008) and do not explicitly consider or measure machinery service usage (for exceptions, see Jetté-Nantel, Hu and Liu 2014 and Ji, Yu and Zhong 2012). Even though Chinese farmers access machinery rental services in addition to owned machinery, land fragmentation is still believed to hinder the use of both machinery sources because fragmented lands require extra labor and fuel inputs, extra time traveling from one plot to another, and heightened skill to accommodate machinery to small, irregularly shaped fields (Bentley 1987).

The purpose of this paper is to model farmer machinery use as a function of agricultural land fragmentation and to trace the effect of machinery use to farm crop production. Our approach focuses on the machinery use because it is critical to rural development in China but rarely studied and the negative effect of land fragmentation is especially serious for regions with a more mechanized agriculture (Kawasaki 2010; Rao 2014).[2] We use instrumental regression and first-difference methods to explore whether reduced land fragmentation stimulates use of agricultural machinery and whether machinery use improves crop production with a recent farm-level data set from two Chinese provinces. Instruments are required because the degree of fragmentation across the lands operated by a farmer may be driven by the same unobservable characteristics that drive machinery use (e.g., managerial capability). To isolate the effect of machinery and other variable inputs on crop production, we estimate a model of the difference in normalized production between two crops grown consecutively on the same plots in the same year.

The contributions of our work are several. First we provide one of the few estimates of how the fragmentation of land operated by farmers affects machinery demand in key agricultural provinces in China. Second, we employ an identification strategy during estimation that is novel to the Chinese context. Specifically, we instrument land fragmentation on operated lands with land fragmentation on owned lands (land with long-term assignment). This strategy recognizes that many farmers operate fewer or more

[2] Land fragmentation might also affect other inputs such as labor and fertilizer, but these are beyond the discussion of this paper.

plots than are currently part of their long-term land allocation. We argue that land fragmentation on owned land results from historical processes that are largely exogenous to unobserved farmer characteristics driving machinery use. Previous research on land fragmentation and productivity (Jetté-Nantel, Hu and Liu 2014; Tan et al. 2008; Wan and Cheng 2001) has relied on stochastic frontier models. As is common in this literature (Mutter et al. 2013), these efforts often fail to account for potential endogeneity, i.e., fail to consider that the inefficiency and error terms can be correlated (Karakaplan and Kutlu 2013). Finally, we account for correlation between production shocks, accumulation of asset stocks and planting decisions (Foster and Rosenzweig 1996) and measurement error (Ashenfelter and Krueger 1994) to check the robustness of our key results.

We find that consolidating an average farm of 0.31 hectares from 2.28 plots to one plot increases machinery use by about 10% and that a 10% increase of machinery use increases crop production between 0.5% and 1%. This contrasts with the results from Wu et al. (2005) who found that land fragmentation did not have significant impact on Chinese crop production in the 1990s. This difference may stem from changes in surplus rural labor in China that occurred since the 1990s. What is more, our findings are lower than the production gain from a complete consolidation estimated by Wan and Cheng (2001) and Jetté-Nantel, Hu and Liu (2014) using Chinese data. This difference may come from our more narrow focus, i.e., that our estimates only take into account the effect of land fragmentation through the channel of machinery use, and our correction for endogeneity, i.e., their stochastic frontier models fail to account for the biasing effects of unobserved farmer characteristics. Compared with results from India provided by Monchuk, Deininger and Nagarajan (2010), our findings are within their range of 0.5% to 2.5% gain from a complete consolidation using different measures of land fragmentation. Despite the different methodological approach followed, our findings are also supported by Liu et al. (2013) and Jetté-Nantel, Hu and Liu (2014) using this same data set. They found that an increased labor price increases farmers' adoption of large machinery and large machinery is associated with higher productivity on larger plots, which may indirectly suggest that land fragmentation may hamper the diffusion of larger machinery.

The remainder of the paper is organized as follows. The next two sections describe institutional background and the data. The next section examines the impact of land fragmentation on machinery use. This is followed by a section exploring how machinery use affects crop production. Both sections include model specification, regression results and robustness checks. The final section provides discussion and conclusions.

2. Institutional background

In the 1950s, agricultural production in China was organized under the "people's communes" system. In this system, the commune was the decision making unit and the output was equally distributed among workers. Therefore, the incentive to work was low and agricultural productivity was stagnant under such collectivization (Lin 1988). In the late 1970s and early 1980s, the Household Responsibility System (HRS) was established. Under this system, the land was still owned by the collective but it was contracted to households on a per capita basis. Individuals of a former commune were entitled to the use of an equal share of the land (Kung and Liu 1997). As a result, the basic decision-making unit was shifted from the collective to individual households. Households could make their own input decisions and receive all the residual income from the land after meeting the tax and quota sales obligations to the state (Almond, Li, and Zhang 2013; Perkins 1988). This institutional reform greatly improved productivity (Lin 1992), but it also led to substantial land fragmentation (Nguyen et al. 1996; Wan and Cheng 2001).

Because land ownership remains collective, local leaders retain power to reallocate land and regularly do so (Jacoby, Li, and Rozelle 2002; Wang et al. 2011). Scholars suggest several motivations for such land reallocation. The first one is the expiration of the initial land allocation contracts, which began expiring in 1988 (Wang et al. 2011).[3] The second is the egalitarian distribution of land in the face of household level demographic change (Kung 1994). Collective ownership is based on values that all village members are entitled to communal rights and equal access to production resources (Wang et al. 2011). Land equality is especially important because land is not only a factor of production but also serves as insurance and food-security for farm households (Park, 1996). Land reallocation helps maintain land equality by shifting land from a household where a death has occurred or where a daughter has married out of the village, to a household where an infant has been born or where a man has gained a wife from another village (Brandt et al. 2002). The third is village leaders' use of land reallocations as "carrot and stick" to fulfill output quotas and collect taxes (Rozelle and Li 1998). However, frequent reallocation undermines tenure security and discourages investment in agriculture, resulting in lower productivity (Jacoby, Li, and Rozelle 2002; Prosterman, Hanstad, and Li 1996).

To address the deleterious effects of frequent land reallocation, the Chinese government

[3] The central government's policy outlined 15 year contracts, but implemented contracts varied across communities (Brandt et al. 2002).

modified its agricultural policies and promulgated the Rural Land Contract Law in 2002, which mandated that farmland tenure security must be maintained for at least 30 years starting from 1998. In 2008, the government further extended land tenure contracts[4] from 30 years to an unspecified "long term" (Wang et al. 2011). In addition, the agricultural output quota system was abandoned in 1985 while farmers have been exempt from agricultural taxes since 2006, meaning village claims on agricultural production and revenue are minimal. Taken together, the government measures suggest highly stable farmers' usage rights of agricultural land.

In recent years, the deepened reform of rural land market has been underscored by each year's No. 1 Central Document, i.e., the initial annual policy document put forth by the Central Committee of the Communist Party of China. Especially in 2014, farmers' land-use right can be subcontracted, leased, exchanged and pledged. Entrepreneurial farmers are encouraged to build up their family farms by renting land from neighbors. In recent months, at least nine of China's 31 provincial governments, including the two provinces from which our data is drawn, have published guidelines for giving subsidies and other support to family farms (The Economist, May 2014). This increases the latitude for reducing land fragmentation.

3. Data

The data come from a survey conducted by researchers from the China Agricultural University to understand the factors that influence farmers' agricultural machinery demand in the provinces of Hebei and Shandong (Liu 2008). The data include detailed information from

[4] Farmers don't pay rent or any other fees to access their allocated lands. While the ownership of all rural land belongs to the collective, farmers retain the usage right.

the year of 2007 regarding household socio-economic characteristics, land characteristics, and production inputs and outputs for wheat and corn. Wheat and corn are two of the most important crops in China, accounting for 52% of total grain output (National Bureau of Statistics 2008). Hebei and Shandong are major wheat and corn producers. In 2007, Hebei and Shandong accounted for 29.2% of the country's total wheat production and 21.3% of the country's total corn production (National Bureau of Statistics 2008). Hebei and Shandong possessed a total machinery power of 91.3 and 99.1 million kilowatts respectively, which rank the second and first among provinces nationally in 2007 (National Bureau of Statistics 2008).

A stratified multistage sample including 550 households was drawn in July 2008 from farms located in these provinces. In each province, counties were divided into three groups (low, medium and high) according to the intensity of machinery capacity use per unit of rural labor. One county was randomly chosen from each group for a total of six counties. Next, three villages were randomly selected from each county. One village in Shandong province had only a dozen households, so it was combined with a nearby village, resulting in a total of 19 villages. Finally, about 30 households were selected from each village (See Liu et al. 2013 for additional details).

Descriptive statistics (Table 1) include three parts: household characteristics, land characteristics and production characteristics. *Machinery owned* represents the total capacity in horsepower the household has purchased and *family labor* is the number of people aged 15-65 years old inclusive.

Table 1: Descriptive Statistics

Variable	Description	N	Mean	S.D.
Household characteristics				
Age	years	550	48.32	10.35
Education	years	550	6.87	3.04
Communist party member	yes=1, no=0	550	0.15	0.36
Training	yes=1, no=0	550	0.27	0.44
Machinery owned	horsepower	550	26.15	39.14
Family labor	# age >14 & <66	550	3.37	1.14
Land characteristics				
Total owned area	mu	550	5.56	3.41
Total owned plots	# of plots	550	2.90	1.72
Total operating area (wheat)	mu	547	4.51	2.65
Total operating plots (wheat)	# of plots	550	2.21	1.30
Total operating area (corn)	mu	548	4.77	2.98
Total operating plots (corn)	# of plots	550	2.34	1.46
Owned land fragmentation	Total owned plots / Total owned area	547	0.56	0.32
Operating land fragmentation (wheat)	Total operating plots (wheat) / Total operating area (wheat)	547	0.58	0.36
Operating land fragmentation (corn)	Total operating plots (corn) / Total operating area (corn)	548	0.57	0.35
Production characteristics				
Wheat horsepower used	horsepower	550	224.86	164.20
Wheat seed cost	yuan	550	161.02	140.01
Wheat fertilizer cost	yuan	550	715.75	521.54
Wheat pesticide cost	yuan	541	93.18	81.21
Wheat irrigation cost	yuan	550	277.94	261.80
Wheat labor	days	547	128.25	106.47
Wheat machinery price	yuan	547	0.89	0.61
Wheat labor price	yuan	547	40.71	10.45
Wheat output	jin	547	3777.06	2231.00
Corn horsepower used	horsepower	550	143.97	128.41
Corn seed cost	yuan	550	134.77	99.33
Corn fertilizer cost	yuan	550	607.93	505.63
Corn pesticide cost	yuan	541	120.36	124.81
Corn irrigation cost	yuan	550	210.13	227.59
Corn labor	days	548	145.19	131.73
Corn machinery price	yuan	522	1.40	1.31
Corn labor price	yuan	547	40.71	10.45
Corn output	jin	548	4458.35	2798.56

Note: † Training is usually organized by government. It includes topics on use, maintenance and repair of agricultural machinery. ‡ Wheat (corn) output refers to the output from wheat (corn) growth circle.

In the land characteristics section, *total owned area* measures the total area in *Mu*[5] that the household is entitled to use after the land distribution in 1978 and any subsequent land adjustment.[6] Similarly, *total owned plots* measures the number of plots that contains the household's land holdings.

Total operating area (wheat or corn[7]) measures the land that farmers used to grow wheat or corn in 2007. These values might be larger than the *total owned area* if farmers rent more land from others to grow wheat or corn, or less than the *total owned area* if farmers lease some of their owned land out. Similarly, *total operating plots* (wheat or corn) measures the number of fields farmers used to grow wheat or corn. Likewise, these values might be larger or smaller than *total owned plots*.

Owned land fragmentation is defined as *total owned plots* divided by *total owned area*, and *operating land fragmentation* (wheat or corn) is defined as *total operating plots* (wheat or corn) divided by *total operating area* (wheat or corn). In contrast to adopting average plot size or Simpson index to capture land fragmentation, this definition of land fragmentation is adopted for three reasons. First, this measure conveys the concept of land fragmentation in an intuitive way. Given the total area (S) and the number of plots (N), land fragmentation (F) can be expressed as N/S. Given S fixed, the more plots farmers have, the greater the fragmentation is. Second, it facilitates the interpretation of estimation results and policy implications (Wan and Cheng 2001). For example, elimination of land fragmentation can be

[5] 1 Mu = 0.067 Hectare

[6] The collective continues to own all land in China. We use "owned" land to refer to the land to which the farmer has the long-term usage right. Farmers do not pay for "owned" land.

[7] Wheat and corn production in Hebei and Shandong provinces occur within a double cropping system. Winter wheat is sown in October and harvested in June of the next year. This is followed by the planting of corn, which is harvested in late September. *Total operating area (wheat)* only counts operating area in wheat growth cycle, and *total operating area (corn)* only counts operating area in corn growth cycle.

simply interpreted N=1 and F approaches zero when the area (S) grows larger. As another example, it is easier for policy makers to set and implement targets on average plot numbers rather than the average plot size. In fact, it is impossible to set a target on the average plot size because average household possession of land differs significantly from village to village. Third, the Simpson index combines two fragmentation dimensions, plot numbers and variability in area, which tend to move the index in different directions and may frustrate interpretation for policy purpose (see Monchuk, Deininger and Nagarajan 2010 for details).

In the production characteristics section, *wheat horsepower used* measures the total machinery use by horsepower used to plow, sow and harvest. In each of these processes, the questionnaire asks farmers the number of hours each machine is used (e.g., 2 hours plowing, 1 hour sowing and 3 hours harvesting) and each machine's work capacity (e.g., 30 horsepower, 25 horsepower and 75 horsepower). *Wheat horsepower used* is calculated by multiplying each machine's capacity by its hours of use (e.g., 2×30+1×25+3×75=310 horsepower). *Corn horsepower used* is measured similarly. Other inputs such as seed, fertilizer, pesticide and irrigation are measured in market value. *Wheat (corn) labor* is the product of the number of people who work on wheat (corn) production and the days they spend on it. *Wheat (corn) machinery price* is average cost of using wheat (corn) machinery per hour. *Wheat (corn) labor price* measures the daily wage of hired farm workers.

4. Land fragmentation and machinery use

4.1 Model specification

We began by specifying machinery horsepower demanded by farm *i* for wheat as,

(1) $$\ln(m_i) = \alpha + \beta f_i + \delta A_i + \varphi' P_i + \gamma' X_i + \theta' V_i + \varepsilon_i$$

where m_i represents horsepower used and f_i is operating land fragmentation. The land fragmentation coefficient (β) is expected to be negative. A_i is total wheat operating area. P_i is a vector of input prices. X_i is a set of control variables including household characteristics. V_i is a vector of village dummies. α is the intercept and ε_i is error term, which consists of factors that drive machinery demand that are unobserved by the researcher. This specification is repeated for corn.

A central concern in estimating equation (1) is the possibility that land fragmentation is driven by some of the same unobserved factors (e.g., management ability) that drive machinery demand. If ε_i is correlated with land fragmentation (f_i), then the OLS coefficient (β) will be biased. The direction of bias is not obvious because more able farmers might use more machinery or less; and more able farmers might attempt to reduce operating land fragmentation or grow more crops that happen to be in separate parcels (which increasesf_i). We address this concern by instrumenting the *operating land fragmentation* with the *owned land fragmentation*. The *total operating area* is also likely endogenous because it is a function of *operating land fragmentation*. We instrument the *total operating area* with *total owned area*.

To evaluate the appropriateness of *owned land fragmentation* as an instrument, we briefly review key aspects of the land distribution process. Recall that farmers obtain their owned land mainly from three sources: land distribution at the onset of the HRS, following demographic changes, and following the formation of new households after marriage. These processes determine the level of owned land fragmentation. Given their land allocation, farmers then decide what crop to plant, which plots to plant on and whether to rent land.

These processes determine the operating land fragmentation (wheat and corn). While the operational land fragmentation may be driven by unobserved characteristics such as management capability, we argue that owned land fragmentation can serve as an instrument because it is exogenously imposed through a process shaped by a combination of population pressure, land scarcity and egalitarian redistribution ideals in the context of an incomplete land market. This idea of utilizing *owned land fragmentation* in this Chinese context is quite similar with using inherited land as instrument for operating land in a private-land-holding economy (Foster and Rosenzweig 2011) but distinct because *owned land fragmentation* in China results from egalitarian land distribution ideals at village and household level.

When HRS was initiated, land was distributed to households by village leaders according to the principle of egalitarianism with adjustments for family size, demographic composition, and labor supply (Putterman 1993). Explicitly, local lands are divided into several classes according to their quality; each person in the household received an equal share of each class of land. This process was exogenous from an individual's perspective because land is regarded as a production factor assuring subsistence. Even if some villages used unequal methods to decide the amount of land to distribute to a given household, the individual land parcels were still randomly assigned by lottery (Liu, Carter and Yao 1998).[8] In both cases, land distribution is independent of individuals' ability.

A second land distribution process comes from land redistribution resulting from the pressure of land inequality after demographic changes (Liu, Carter and Yao 1998). This

[8] Liu, Carter and Yao (1998) summarized four methods used to allocate land of different qualities in rural China. Since the formation of land use right is not the main focus of this study, we don't provide detail discussions on this. The surveyed villages in Hebei and Shandong are agriculturally dependent and their egalitarian distribution of land is consistent with Liu, Carter and Yao (1998) that more than 90% of the agriculturally dependent villages in Jiangxi, Henan and Jilin provinces utilized egalitarian methods to allocate land.

process is also exogenous from the individual's perspective because households have limited control of family population growth under the restriction of one-child policy. Also, as we discussed in the institutional background, this land reallocation process was forbidden by the Land Management Law (1998), Rural Land Contract Law (2002) and Property Law (2007). This suggests highly stable farmers' usage rights of agricultural land.

Another land distribution process comes from inheritance or formation of new households after marriage. As was the case under the HRS, land was distributed by the head of a household equally among sons because of egalitarianism (Tao 2013). This also helps avoid the potential tension caused by unequal duties of supporting the old because of the unequal distribution of land (Tao 2013). In addition, lands, by law, are still owned by the collective and cannot be sold even if farmers move to urban areas. This also intentionally prevents the change of land usage right.

However, Blarel et al. (1992) argues that, instead of exogenous imposition, land fragmentation might be endogenously demanded by farmers because it is beneficial in managing risk, overcoming seasonal labor bottlenecks, and better matching soil types with necessary food crops. This is not the case in Hebei and Shandong provinces in China for three reasons. First, it is not likely for natural disasters to strike one parcel while others are spared within villages in North China Plain (Wan and Cheng 2001). Therefore, fragmentation is an ineffective method to reduce risk in Hebei and Shandong. Even if land fragmentation does reduce production risk, its monetary value is far below the cost of land fragmentation (Kawasaki 2010). Second, farmers in Hebei and Shandong grow wheat and corn in different seasons on the same plots, which means land fragmentation has no contribution to overcoming seasonal labor bottlenecks. Finally, sufficient soil quality heterogeneity can exist in a single large piece of land so that farmers can still match soil types with necessary food crops. These factors undermine the argument that fragmentation contributes to better matching of soil and crops.

4.2 Results and discussion

Table 2 presents the coefficient estimate from equation (1) with different specifications. The first two columns are the basic results from OLS. Land fragmentation has significant negative effects on machinery use. A one unit increase of land fragmentation reduces machinery use by 23.2% and 30% for wheat and corn, respectively. This is consistent with the rational that land fragmentation causes extra labor and fuel inputs, the time wasted traveling from plot to plot, or the difficulty of accommodating machinery to small, irregularly shaped fields.

Column (3) and (4) present the results after instrumenting *operating land fragmentation* and *total operating areas* with *owned land fragmentation* and *total owned area*, respectively. Based on the IV estimation, a one unit increase of land fragmentation reduces machinery use by 37% and 34% for wheat and corn, respectively. This implies that consolidating an average farm of 0.31 hectares from 2.28 plots to one plot increase machinery use by 9.74% on average.[9] Compared with above OLS results, the effect of land fragmentation is more negative, which is consistent with an attenuation bias for OLS estimate. This may suggest more able farmers use more machinery and they grow more crops but in separated parcels (which increases fragmentation). Another possible explanation is that more able farmers

[9] The average household operating areas for wheat and corn are 4.51 mu and 4.77 mu, and their average is 4.64 mu (0.31 ha.). The average plots for wheat and corn are 2.21 and 2.34. Consolidating all plots into one piece will increase machinery usage by ((2.21-1)/4.51)* 37%=9.93% and ((2.34-1)/4.77)*34%=9.55% for wheat and corn, respectively, and their average is 9.74%.

spend more time in off-farm work and, therefore, grow fewer crops and use less machinery; at the same time, they try to reduce land fragmentation.

Table 2: Regression Results for Machinery Use

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV	IV	IV	IV
Ln(machinery use)	**Wheat**	**Corn**	**Wheat**	**Corn**	**Wheat**	**Corn**
Independent variables						
Land fragmentation	-0.23***	-0.30***	-0.37***	-0.34***	-0.36***	-0.34***
(# plots/Mu)	(-4.40)	(-4.18)	(-4.04)	(-3.32)	(-4.00)	(-3.32)
Total operating area	0.18***	0.17***	0.17***	0.19***	0.18***	0.19***
(Mu)	(20.42)	(14.50)	(7.73)	(7.27)	(9.98)	(8.60)
Machinery price	-0.66***	-0.39***	-0.65***	-0.40***	-0.66***	-0.40***
(per horsepower)	(-13.46)	(-12.87)	(-11.91)	(-13.53)	(-12.62)	(-13.39)
Labor price/1000	1.02	3.84*	0.40	4.15**	0.63	4.50**
(per day)	(0.72)	(1.90)	(0.28)	(1.99)	(0.44)	(2.21)
Family labor	0.03**	0.02	0.04**	0.01		
(# >14 & <66)	(2.79)	(1.06)	(2.50)	(0.42)		
Age/1000	-1.55	-1.82	-1.36	-2.11		
	(-1.06)	(-0.69)	(-0.93)	(-0.82)		
Education/1000	-3.67	0.33	-4.58	0.19		
	(-0.83)	(0.05)	(-1.03)	(0.03)		
Party member	0.04	-0.02	0.04	-0.03		
(yes=1, no=0)	(1.12)	(-0.36)	(1.28)	(-0.58)		
Training	0.02	0.05	0.02	0.05		
(yes=1, no=0)	(0.62)	(1.16)	(0.59)	(1.19)		
Machinery owned /1000	-0.15	-0.10	-0.05	-0.18		
(horsepower)	(-0.51)	(-0.22)	(-0.18)	(-0.39)		
Constant	4.93***	4.34***	5.19***	4.27***	5.06***	4.19***
	(31.88)	(19.87)	(23.41)	(15.15)	(24.55)	(15.76)
Village dummy	yes	yes	yes	yes	yes	yes
Observations	547	518	544	515	544	515
R-square	0.86	0.83	0.86	0.82	0.85	0.82
Partial F (predicting land fragmentation)			143.45	167.75	141.19	178.37
Partial F (predicting area)			43.78	51.57	68.17	76.70
Endogeneity test (p value)			0.03	0.16	0.03	0.10

Notes: † The partial F statistics are obtained from the first stage of 2SLS instrumenting operating land fragmentation and total operating area, respectively. ‡ Standard errors are corrected for heteroskedasticity and t values are reported in brackets. § The detail results of first stage of 2SLS regression are available upon request.

* significant at 10% level; ** significant at 5% level; *** significant at 1% level.

Column (5) and (6) check the sensitivity of the instrument regression after excluding some household variables. A similar negative impact of land fragmentation on machinery use is found here. This suggests that the instruments are not substantially influenced by other observed variables, which is indirect evidence that the instruments are independent of the error term. The relevance test and endogenous test of IV regression are presented at the last two rows of table 2. All partial F statistics exceed 10, and the endogeneity tests (Baum, Schaffer, and Stillman 2003, 2007) reject that the estimated OLS and IV coefficients are the same at 5% level for wheat and at looser levels for corn.

4.3 Robustness

A potential weakness in this identification strategy arises if local authorities' decisions were systematically influenced by unobserved characteristics in a manner that consistently led to more or less fragmentation. It is not clear to us whether such criteria were used by local authorities and, if there were, whether, for example, good managers would be given additional adjacent lands, hence limiting fragmentation, or just given more land wherever it was available, most likely increasing fragmentation.

We argue that, even if land allocation was not totally egalitarian, it does not necessarily mean that the unobservables that affected land allocation (most likely before 2004[10]) also drove machinery use in 2007. If the unobservable is correlated with land allocation, it must be correlated with the factors that drive land allocation or result from land allocation. Family population change is the main reason why land needs to be reallocated. The growth of

[10] Although some villages still adjusted land for the purpose of land equality, the frequency of land reallocation decreased greatly since 1998 and it seldom happened after 2004. As evidence, one 2005 nationwide survey (Feng et al. 2011) shows that, from 1998 to 2004, 36.9% of villages had land reallocation and the average frequency was 2.2. Their following 2008 nationwide survey shown that, from 1998 to 2007, 37.5% of villages had land reallocation and the average frequency was 2.4. That means, from 2004 to2007, only 0.6% villages with the frequency of 0.2 had land reallocation and these were mostly small adjustments.

non-farm income may reduce farmers' dependence on farm and incentive on farm work, especially when their fragmented land is not as productive as others'. If the unobservable also affects machinery use, adding or deleting family population and non-farm income will change the coefficient in front of land fragmentation, but we found the coefficients are little changed (results available upon request).

To further check exogeneity, we also use measures of some exogenous causes to predict the *owned land fragmentation*, and then use the *predicted owned land fragmentation* as an instrument for *operating land fragmentation.*[11] Those exogenous causes include road length[12], arable land, and population[13] at town level in 1978. Compared with results in Table 2, the coefficient for land fragmentation, using *predicted owned land fragmentation* as an instrument, is significant and in the same direction, though the magnitude is larger (results available upon request). This strengthens our claim that *owned land fragmentation* is a good instrument for *operating land fragmentation*.

5. Machinery use and crop production

5.1 Model specification

This section investigates the impact of machinery use on crop production. The following model of production for farm *i* and crop *j* is specified,

(2) $$Q_{ij} = \alpha_j + \rho_j m_{ij} + \zeta_j' I_{ij} + \gamma_j' X_{ij} + \theta_j' V_{ij} + \varepsilon_{ij} \quad j \in \{wheat, corn\}$$

[11] Similarly, we also use exogenous causes to predict the *total owned area*, and then use the *predicted total owned area* as an instrument for *total operating area*.

[12] Road length measures the distance between the town and its nearest urban center. It affects rural development through many channels, such as alleviating poverty, increasing market access, increasing rural nonfarm employment, and rural migration into urban sectors (Barrios 2008; Fan and Zhang 2004; Fedderke, Perkins, and Luiz 2006; Gibson and Rozelle 2003; Zhao 1999). All these changes have an influence on demographic changes and land markets, and, as a result, may affect owned land fragmentation (Tan, Heerink, and Qu 2006).

[13] Arable land and population represent the degree of population pressure and land scarcity when the HRS was initiated.

where Q_{ij} represents the crop output (in jin[14]) and m_{ij} measures machinery use in horsepower. The coefficient on machinery use (ρ) is expected to be positive. I_{ij} is a vector of all other inputs including seeds, fertilizer, pesticide, irrigation and labor. X_{ij} is a set of variables including household characteristics and land characteristics. V_{ij} is a vector of village dummies, which controls for village level heterogeneity. α_j is the intercept and ε_{ij} is the error term. All variables in this section are mean centered and normalized by first subtracting the means and then divided by the means.[15] Therefore, the estimation coefficients can be interpreted as percentage changes.

The coefficients in equation (2) are also subject to omitted variable bias since individual ability is unmeasured. We address this issue by first-difference estimation utilizing the fact that farmers grow wheat in autumn and corn in spring on the same plots. Specifically, equation (2) can be rewritten as two equations for wheat and corn, respectively. For wheat, the production function for farm *i* is,

(3) $$Q_{iw} = \alpha_w + \rho m_{iw} + \zeta' I_{iw} + \gamma' X_i + \theta' V_i + u_i + \varepsilon_{iw}$$

where subscript w refers to wheat and u_i is farmer's ability. For corn, the production function is

(4) $$Q_{ic} = \alpha_c + (\rho + \eta_m) m_{ic} + (\zeta + \eta_I)' I_{ic} + (\gamma + \eta_X)' X_i + (\theta + \eta_v)' V_i + u_i + \varepsilon_{ic}$$

where subscript c refers to corn. The η's capture the differences in marginal productivity (different mappings[16]) for each input between wheat and corn production.

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[14] 1 jin=0.5 kg.

[15] We also try to divide the mean centered variables by their standard errors. There are no substantial changes in the results. For interpretation purpose, we use this de-mean/mean version

[16] Broadly speaking, a technology means a mapping between inputs and outputs (Foster and Rosenzweig 2010). Here corn production can be viewed as a similar production process as wheat but using different types of technologies. Following Foster and Rosenzweig (1996) when estimating the relationship between technical change and human-capital returns, this paper uses η's to capture the different marginal productivity (which means different mappings) between wheat and corn production.

The difference between equation (3) and (4) is

$$\Delta Q_i = \Delta\alpha + \rho\Delta m_i - \eta_m m_{ic} + \zeta'\Delta I_i - \eta_I' I_{ic} - \eta_X' X - \eta_v' V + \Delta\varepsilon_i \quad (5)$$

The first-differencing is equivalent to the inclusion of household fixed effects in a level regression; the estimates are therefore purged of time-invariant abilities (u) across households. The constant term ($\Delta\alpha$) in equation (5) is equivalent to including a season fixed effect in a level regression. One advantage of the first-difference estimation is that it allows the inclusions of village dummies (V) which will be eliminated by household fixed effects. The coefficients η_v in front of village dummies capture the different marginal productivity in producing wheat and corn at the village level because of soil characteristics, climate, natural disaster or local policies.

One assumption that has been made here is that the individual ability has the same marginal effects on both wheat and corn such that the ability (u) will be eliminated after taking difference. Several previous studies have made similar assumptions. For example, when Blarel et al. (1992) estimate the impact of farm fragmentation on crops yield, if certain variables are not crop-specific, they stack the separate crop yields into a single regression. No household or farm variables are considered to be crop-specific, suggesting that household and farm variables have identical marginal effects on different crop yields. Foster and Rosenzweig (1995) combine wheat and rice data in the same regression. The underlying assumption is that the returns to experience are the same for wheat and rice and that experience with the two crops are perfect substitutes. Monchuk, Deininger and Nagarajan (2010) aggregate the value of different outputs into a single measure, indicating inputs have the same marginal effect on output for different crops. Jetté-Nantel, Hu and Liu (2014), to minimize the information loss, estimate a joint stochastic frontier model based on the assumption that the inefficiency terms for wheat and corn are identical.

This assumption is indirectly tested by gauging the stability of the regression results after excluding household variables that are correlated with ability in equation (5). If ability information is still included in the residuals after first differencing (which means individual ability has different effects on wheat and corn outputs such that first difference cannot remove it), deleting or adding those ability related variables (including education, age, training and party membership) should alter the estimated coefficient in front of machinery use. If the estimated impact of machinery use on output changes very little when those household characteristics are excluded from regressions, we feel more confident that the omitted ability information is fully removed.

Another way to test the above assumption is to test the significance of the coefficients of household characteristics (X) in equation (5). If η_x are not significantly different from zero, we cannot reject the household characteristics have identical marginal effects on wheat and corn outputs. This serves as indirect evidence that the unobservable ability has identical marginal effect on wheat and corn outputs.

5.2 Results and Discussion

Table 3 presents the results of OLS and first-difference estimation. In the OLS regression (column 1 and 2), a 10% increase in machinery use increases crop production by 1% and 0.8% for wheat and corn, respectively. In the first-difference estimation (column 3), a 10% increase in machinery use increases crop production by 0.5% for both wheat and corn.[17] The direction

[17] It needs to be noted that the coefficient of *Corn horsepower used* is 0.00 and not significant, indicating that machinery use has identical effects on both wheat and corn production.

Table 3: Regression Results: Crop Production

	(1)	(2)		(3)	(4)
	OLS	OLS		First difference	First difference
	Wheat output	Corn output		Δ output	Δoutput
Horsepower used	0.10**	0.08*	Δ horsepower used	0.05*	0.05**
	(2.21)	(1.68)		(1.89)	(2.03)
Seed cost	0.11*	0.49***	Δ seed cost	0.08***	0.08***
	(1.91)	(4.10)		(6.05)	(7.16)
Fertilizer cost	0.28***	-0.12***	Δ fertilizer cost	0.15***	0.14***
	(9.06)	(-3.09)		(3.60)	(3.18)
Pesticide cost	0.08**	0.02	Δ pesticide cost	0.11***	0.10***
	(2.12)	(0.34)		(4.67)	(4.34)
Irrigation cost	0.11***	-0.03	Δ irrigation cost	0.07*	0.07*
	(7.33)	(-0.94)		(1.78)	(1.81)
Labor	0.11***	0.15**	Δ labor	0.09***	0.10***
	(8.62)	(2.40)		(4.72)	(4.93)
Age	-0.00	-0.04	Age	0.04	
	(-0.06)	(-0.69)		(1.62)	
Education	-0.01	0.03	Education	-0.03***	
	(-0.33)	(0.45)		(-3.04)	
Party member	0.01	0.01**	Party member	0.00	
	(1.61)	(2.19)		(0.65)	
Training	-0.00	-0.00330	Training	0.00	
	(-0.23)	(-0.28)		(0.19)	
Machine owned	0.01	0.00	Machine owned	0.01	
	(1.27)	(0.03)		(1.61)	
Land quality	0.03	0.03	Land quality	-0.04	
	(0.69)	(0.42)		(-1.56)	
Family labor	0.05***	0.16***	Family labor	-0.06***	
	(2.79)	(2.84)		(-4.21)	
			Corn horsepower	0.00	0.00
			used	(0.11)	(0.05)
			Corn seed cost	-0.02	-0.02
				(-0.37)	(-0.38)
			Corn fertilizer cost	0.04	0.03
				(1.17)	(1.07)
			Corn pesticide cost	0.04***	0.04***
				(2.95)	(2.64)
			Corn irrigation cost	-0.02	-0.02
				(-1.59)	(-1.57)
			Corn labor	-0.01	-0.01
				(-0.32)	(-0.38)
Constant	-0.00	0.01		-0.00	-0.00
	(-0.07)	(0.16)		(-0.10)	(-0.08)

Observations	538	538		534	537

Notes: † All regressions include village fixed effects and t values are reported in brackets. ‡ Standard errors clustered at the county level are computed and cluster bootstrap method is utilized to account for small size of counties and heteroskedasticity.

* significant at 10% level; ** significant at 5% level; *** significant at 1% level.

of bias is positive in OLS regressions because more able farmers use more machinery and have higher productivity. In column 4, after excluding variables that are likely to be correlated with ability, the coefficient of machinery use is very stable; this supports our assumption that omitted ability is eliminated after first differencing. In addition, most ability related variables (especially age, the proxy for farming experience) are not significant; this also supports that ability information is absent from the residuals. Although the coefficient of education is significant in column (3), it is still safe to say ability information is removed from residuals because farm work requires more specific farm experience and education is not as good of a proxy as age or training for farm experience. Besides, this finding is similar with research from Rahman and Rahman (2009) that a 10% increase in the adoption of modern technology improves efficiency by 0.4% in Bangladesh.

5.3 Robustness

Following Foster and Rosenzweig (1995 and 1996) and Ashenfelter and Krueger (1994), estimation of equation (5) will not necessarily yield consistent estimate of coefficients for three reasons. First, the shocks in the initial period are likely to be correlated with the change in accumulated asset stocks over the interval and the machinery use in the second period. Second, if some component of the shock is known prior to planting, then there will be a contemporaneous correlation between production shocks and planting decisions[18]. Third, the first-difference estimation usually exaggerates measurement error, resulting in attenuation bias.

Table 4: Robustness Check of the Effect of Machinery Use on Crop Production

	Obs.	Δ horsepower used	z-value
Δ output 1 (without purchase)	504	0.053*	(1.88)
Δ output 2 (wheat shock 5%)	509	0.076*	(1.88)
Δ output 3 (wheat shock 10%)	483	0.075**	(2.06)
Δ output 4 (wheat shock 25%)	402	0.073**	(2.38)
Δ output 5 (corn shock 5%)	508	0.058**	(2.12)
Δ output 6 (corn shock 10%)	483	0.055*	(1.88)
Δ output 7 (corn shock 25%)	403	0.062**	(2.19)

Notes: † Δ output 1 excludes observations that purchased machinery in 2007; Δ output 2, Δ output 3 and Δ output 4 represent excluding observations with wheat income difference in the top 5%, 10% and 25% of the sample population, respectively; Δ output 5, Δ output 6 and Δ output 7 represent excluding observations with corn income difference in the top 5%, 10% and 25% of the sample population, respectively. ‡ All regressions include village fixed effects. § Standard errors are clustered at the county level and the cluster bootstrap method is utilized to account for small size of counties and heteroskedasticity. ¶ Detail regression results are available upon request.

* significant at 10% level; ** significant at 5% level; *** significant at 1% level.

We address the above issues in several ways. First, the lagged production shock is not likely to affect the accumulation of assets in this study because there is almost no time interval between wheat and corn production. Besides, farmers who purchase machinery (a proxy for asset) in the sample year are excluded to test the stability of the coefficient in front of machinery use. This result is presented in the first row of Table 4. The effect of machinery use on crop production is unchanged. A 10% increase of machinery use increases crop production by 0.53%. It suggests that shocks in the initial period are not correlated with the change in accumulated asset stocks over the interval.

[18] Foster and Rosenzweig (1995 and 1996) suggest that profit shocks might be correlated with accumulated asset and planting decision. Since output and profit are highly correlated, it is also necessary to consider the correlation between production shocks and accumulated asset and planting decision.

Second, if the shock has the same marginal effects on wheat and corn production, then it has already been differenced out in equation (5). If the shock has different effects on wheat and corn production, some component still exists in the residuals of equation (5). For example, the lagged production shock from wheat production might increase the use of corn machinery and corn planting areas. This bias can be indirectly tested by excluding those farmers who have larger fluctuations in planting decisions, machinery use and crop income during the sample periods.[19] Specifically, observations with the top 5%, 10% and 25% net crop income difference (in absolute values) between 2006 and 2007 are dropped. Table 4 presents these results. The effect of machinery use on crop production induces minor changes. A 10% increase in machinery use increases crop production between 0.53% and 0.76%.

Table 5: Results of First-Difference-IV Regression

	Δ output	z-value
Δ horsepower used	0.08	(1.53)
Observations	534	
Partial F in first stage	25.38	
Endogeneity test	0.62	

Notes: † Standard errors are clustered at the county level and the cluster bootstrap method is utilized to account for small size of counties, heteroskedasticity and the fact that difference of horsepower used is a generated regressor. ‡ The prediction results and the first stage of first-difference-IV regression are available on request.

* significant at 10% level; ** significant at 5% level; *** significant at 1% level.

Third, to address measurement error, the *own land fragmentation* is utilized to predict the machinery use for both wheat and corn. Then the difference of predicted machinery use between wheat and corn serves as an instrument for the difference of machinery use in equation (5). Table 5 presents these results. A 10% increase of machinery use increases crop

[19] The data include another two years (2005 and 2006) of retrospective information. The accuracy of retrospective data is usually questioned. However, if there are large fluctuations in planting decisions and crop income in the preceding two years (2006 and 2007), these may be more salient and subject to less recall bias. This study excludes those farmers who have large fluctuations between 2006 and 2007 to test the stability of regression coefficients.

production by 0.8%. This suggests that measurement error does cause attenuation bias but not much in this case. The *p*-value of the test for endogeneity is 0.62, indicating that the difference in machinery use can be treated as exogenous. This is reasonable because the omitted variable bias has already been eliminated by first-differencing. In fact, this IV regression also takes care of the bias caused by production shocks mentioned above.

6. Discussion and conclusions

Using a recent data set from farm households in Hebei and Shandong, this study estimates the effect of land fragmentation on machinery use, and the effect of machinery use on crop production. The main results indicate that consolidating an average farm of 0.31 hectares from 2.28 plots to one plot increases machinery use by about 10%. Further, a 10% increase of machinery use increases crop production between 0.5% and 1%. This value serves as a lower bound of production growth after land consolidation because our estimates only take into account how land fragmentation affects machinery use.

Our findings differ from Wu et al. (2005) which compares 1996 Chinese household data between crop production in areas with and without a land consolidation program. They find that land fragmentation does not have significant impact on crop production. The difference between our results may stem from changes over time. Labor savings generated by increased machinery use may have not been highly valued by farmers in 1990's China, which featured more plentiful rural labor than during the more current period featured in our data. This explanation is consistent with the findings from Tan et al. (2008). With field data from 2000, they find that changes in the number of plots and plot size distribution do not affect total crop production costs per unit output, but did cause a shift from machinery cost to labor cost.

However, as discussed above, China has experienced a sharp decline in the rural labor force (Yang et al. 2013). The impact of land fragmentation on crop production now becomes significant because insufficient surplus labor can compensate the loss from less efficient usage of machinery due to scattered land management. Therefore, the findings in this paper provide a new estimate of the effect of land fragmentation on crop production.

The findings in this paper are consistent with other research findings using this same data set. Jetté-Nantel, Hu and Liu (2014) disaggregate machinery inputs into three categories (large, medium, and small[20]) and find a positive interaction between land size and large machinery in the production function. This suggests that large machinery tends to be a complement to larger plots. Also, Liu et al. (2013) find that an increase in labor price would cause farmers to increase their adoption of large machinery relative to medium and small pieces. This suggests a greater negative effect of land fragmentation because the use of large machinery is more likely to be hampered by small and irregular fields when farmers adopt large machinery to substitute labor. Both of the above findings indirectly support our results by showing that land fragmentation hampers the development of larger machinery.

Similar to Monchuk, Deininger and Nagarajan (2010), the negative impact of land fragmentation on production in this study is significant but small in magnitude. One reason the magnitude might be so small is that household-level analysis cannot account for land exchange between households. Due to the fact each household itself own little land, the potential for productivity gains may be less when only considering the variability of fragmentation within household level land holdings. Further economics of scale could be

[20] Small machinery included machines with less than 14.7 kilowatts. Medium machinery was defined to have between 14.7 and 36.8 kilowatts; and large machinery as more than 36.8 kilowatts (Liu et al. 2013).

achieved if the land consolidated were considered at a village level. Further, the negative impact of land fragmentation could become more serious because fragmented land might also hinder the effect of other policy instruments. For example, machinery subsides are expected to increase machinery demand and reduce machinery rental prices, but land fragmentation could limit the extent of the machinery rental market by hampering machinery use. The analysis of interactions between land consolidation and machinery subsidy policies is a ripe topic for future research.

Some limitations of this study also need to be considered. First, the current measurement of land fragmentation fails to account for geographical information such as plot location, plot distance, plot contiguity, and plot shape. Such considerations may be crucial for local policy makers as they consider various methods of enabling consolidation. Second, it is also necessary to quantify the relationship between land fragmentation and crop production through other inputs, such as labor and fertilizer. Third, although land consolidation may increase farm productivity, the administrative costs of achieving consolidation must also be evaluated as must any other adjustment costs borne by farmers.

References:

Almond, D., Li, H. and Zhang, S. (2013). Land reform and sex selection in China, *National Bureau of Economic Research Working Paper Series* No. 19153.

Ashenfelter, O. and Krueger, A. (1994). Estimates of the economic return to schooling from a new sample of twins, *The American Economic Review* 84, 1157-1173.

Barrios, E.B. (2008). Infrastructure and rural development: household perceptions on rural development, *Progress in Planning* 70, 1-44.

Baum, C.F., Schaffer, M.E. and Stillman, S. (2003). Instrumental variables and GMM: Estimation and testing, *Stata Journal* 3, 1-31.

Baum, C.F., Schaffer, M.E. and Stillman, S. (2007). Enhanced routines for instrumental variables/generalized method of moments estimation and testing, *Stata Journal* 7, 465-506.

Bentley, J.W. (1987). Economic and ecological approaches to land fragmentation: in defense of a much-maligned phenomenon, *Annual Review of Anthropology* 16, 31-67.

Blarel, B., Hazell, P., Place, F. and Quiggin, J. (1992). The economics of farm fragmentation: evidence from Ghana and Rwanda, *The World Bank Economic Review* 6, 233-254.

Brandt, L., Huang, J., Li, G. and Rozelle, S. (2002). Land rights in rural China: facts, fictions and issues, *The China Journal*67-97.

China, National Bureau of Statistics. (2008). *China Statistics Yearbook*. Beijing: China Statistics Press

China, the State Council. (2014). The No. 1 Central Document. Retrieved online July 11, 2014 from http://jjckb.xinhuanet.com/2014-01/19/content_487974.htm

China, the State Council. (2015). The No. 1 Central Document. Retrieved online Jan. 31, 2015 from http://finance.qq.com/a/20141223/061826.htm

Fan, S. and Zhang, X. (2004). Infrastructure and regional economic development in rural China, *China Economic Review* 15, 203-214.

Fedderke, J.W., Perkins, P. and Luiz, J.M. (2006). Infrastructural investment in long-run economic growth: South Africa 1875–2001, *World Development* 34, 1037-1059.

Feng, L., Ye, J., Jiang, Y. and Zhu, K. (2011). The sequential variation and regional difference of land reallocation in rural China: an empirical study based on survey in 17 provinces from 1999 to 2010, *China land Science* 25(5)

Foster, A.D. and Rosenzweig, M.R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture, *Journal of Political Economy* 1176-1209.

Foster, A.D. and Rosenzweig, M.R. (1996). Technical change and human-capital returns and investments: evidence from the green revolution, *American Economic Review* 86, 931-953.

Foster, A.D. and Rosenzweig, M.R. (2010). Microeconomics of technology adoption, *Annual Review of Economics* 2.

Foster, A.D. and Rosenzweig, M.R. (2011). Are Indian farms too small? Mechanization, agency costs, and farm efficiency, *Econojmic Growth Center, Yale University New Haven CT*.

Jacoby, H.G., Li, G. and Rozelle, S. (2002). Hazards of expropriation: tenure insecurity and investment in rural China, *American Economic Review*1420-1447.

Jetté-Nantel, S., Hu, W. and Liu, Y. (2014). Economies of scale and mechanization in corn and wheat production in Chinese agriculture. *Working paper,* Department of Agricultural Economics, University of Kentucky.

Ji, Y., Yu, X. and Zhong, F. (2012). Machinery investment decision and off-farm employment in rural China, *China Economic Review* 23, 71-80.

John Gibson and Scott Rozelle (2003). Poverty and Access to Roads in Papua New Guinea, *Economic Development and Cultural Change* 52, 159-185.

Kawasaki, K. (2010). The costs and benefits of land fragmentation of rice farms in Japan, *Australian Journal of Agricultural and Resource Economics* 54, 509-526.

Karakaplan, M.U. and Kutlu, L. (2013). Handling endogeneity in stochastic frontier analysis: a solution to endogenous education cost frontier models. *Working paper, Department of Economics,* Oregon State University.

Kung, J.K. (1994). Egalitarianism, subsistence provision, and work incentives in China's agricultural collectives, *World Development* 22, 175-187.

Kung, J.K. and Liu, S. (1997). Farmers' preferences regarding ownership and land tenure in post-Mao China: unexpected evidence from eight counties, *The China Journal* 38, 33-63.

Lin, J.Y. (1988). The household responsibility system in China's agricultural reform: a theoretical and empirical study, *Economic Development and Cultural Change*S199-S224.

Lin, J.Y. (1992). Rural reforms and agricultural growth in China, *American Economic Review* 82, 34-51.

Liu, S., Carter, M.R. and Yao, Y. (1998). Dimensions and diversity of property rights in rural China: Dilemmas on the road to further reform, *World Development* 26, 1789-1806.

Liu. Y. 2008. A demand analysis of agricultural machinery in Hebei and Shandong. *Survey*.

Liu, Y., Hu, W., Jetté - Nantel, S. and Tian, Z. (2013). The Influence of Labor Price Change on Agricultural Machinery Usage in Chinese Agriculture, *Canadian Journal of*

Agricultural Economics/Revue canadienne d'agroeconomie.

Liu, Y. and Tian, Z. (2009). The effect of income on demand of agricultural machinery in Hebei and Shandong. *Chinese Rural Economy* 12:44-50

Monchuk, D., Deininger, K. and Nagarajan, H. (2010). Does land fragmentation reduce efficiency: Micro evidence from India. *Agricultural and Applied Economics Association*

Mutter, R.L., Greene, W.H., Spector, W., Rosko, M.D. and Mukamel, D.B. (2013). Investigating the impact of endogeneity on inefficiency estimates in the application of stochastic frontier analysis to nursing homes, *Journal of Productivity Analysis* 39, 101-110.

Nguyen, T., Cheng, E. and Findlay, C. (1996). Land fragmentation and farm productivity in China in the 1990s, *China Economic Review* 7, 169-180.

Otsuka, K. (2013). Food insecurity, income inequality, and the changing comparative advantage in world agriculture, *Agricultural Economics* 44, 7-18.

Park, A. (1996). Risk, Storage, and Grain Storage in China. *Mimeo,* Department of Economics, University of Michigan, Ann Arbor, MI.

Perkins, D.H. (1988). Reforming China's Economic System, *Journal of Economic Literature* 26, 601-645.

Prosterman, R.L., Hanstad, T. and Li, P. (1996). Can China feed itself?, *Scientific American* 275, 70-76.

Putterman, L. (1993). Continuity and change in China's rural development: collective and reform eras in perspective, *OUP Catalogue*.

Rahman, S. and Rahman, M. (2009). Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh, *Land Use Policy* 26, 95-103.

Rao, X. (2014). Land Fragmentation with Double Bonuses--The Case of Tanzanian Agriculture, Proceedings of the 2014 Annual Meeting, July 27-29, 2014, Minneapolis, Minnesota2014. Agricultural and Applied Economics Association.

Rozelle, S. and Li, G. (1998). Village Leaders and Land-Rights Formation in China, *The American Economic Review* 88, 433-438.

Ruttan, V.W. (2000). Technology, growth, and development: an induced innovation perspective, *OUP Catalogue*.

Tan, S., Heerink, N., Kruseman, G. and Qu, F. (2008). Do fragmented landholdings have higher production costs? Evidence from rice farmers in Northeastern Jiangxi province, PR China, *China Economic Review* 19, 347-358.

Tan, S., Heerink, N., Kuyvenhoven, A. and Qu, F. (2010). Impact of land fragmentation on rice producers' technical efficiency in South-East China, *NJAS-Wageningen Journal of Life Sciences* 57, 117-123.

Tan, S., Heerink, N. and Qu, F. (2006). Land fragmentation and its driving forces in China, *Land Use Policy* 23, 272-285.

Tao, Z. (2013). Split and Succession: a Study on the Sustaining Mechanism of Rural Families and on the Regional Types of Rural Families. *PhD dissertation,* Huazhong University of Science and Technology

The Economist. (2014). Agriculture: Bring back the landlord. Retrieved Oct. 28, 2014 from http://www.economist.com/news/china/21601563-officials-want-family-run-farms-gr gr-much-bigger-america-new-model-bring-back

Van Hung, P., MacAulay, T.G. and Marsh, S.P. (2007). The economics of land fragmentation in the north of Vietnam, *Australian Journal of Agricultural and Resource Economics* 51, 195-211.

Wan, G.H. and Cheng, E. (2001). Effects of land fragmentation and returns to scale in the Chinese farming sector, *Applied Economics* 33, 183-194.

Wang, H., Tong, J., Su, F., Wei, G. and Tao, R. (2011). To reallocate or not: Reconsidering the dilemma in China's agricultural land tenure policy, *Land Use Policy* 28, 805-814.

Wu, Z., Liu, M. and Davis, J. (2005). Land consolidation and productivity in Chinese household crop production, *China Economic Review* 16, 28-49.

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

Zhao, Y. (1999). Labor Migration and Earnings Differences: The Case of Rural China, *Economic Development and Cultural Change* 47, 767-782.