Effects of water priority policy on farmers' decision on acreage allocation in northwest China

Lei Zhang[1,2*] and Thomas Herzfeld[3]

[1] Development Economics Group, Wageningen University, The Netherlands
[2] China Centre for Land Policy Research, Nanjing Agricultural University, P.R. China
[3] Department Agricultural Policy, Leibniz-Institute of Agricultural Development in Central and Eastern Europe, Germany
* Corresponding author. Email: lei2.zhang@wur.nl

Abstract:

This article analyses the impact of a water allocation priority policy for a specific crop on farmers' acreage allocation to different crops. To accomplish this, a system of crop acreage demands conditional on output yields, prices of variable inputs and levels of quasi-fixed inputs is estimated. The analysis based on a two-year farm household panel data from an arid region in northwest China. The results show that the water policy change results in a lower elasticity of land demand not only for Atlantic potatoes (i.e. the preferential crop), but also for the other crops. Acreage allocation to grains differs from other crops due to their use within the farm household. Moreover, the estimated elasticities of quasi-fixed inputs reveal that whereas the area of cash crops and Atlantic potatoes increases with increased use of own labour before the policy change, it does so only for cash crops after the policy change. With respect to own and exchanged labour Atlantic potatoes behave like grains and regular potatoes after the policy change.

Key words: water scarcity, priority allocation, agricultural production

1. Introduction

Governments interfere quite often in producer's decision space in agricultural production systems. In this context the access to irrigation water is contested in many countries, the more water becomes a scarce input. For this and other reasons, governments regulate the access to irrigation water. The effects of such interferences, especially related to water entitlements or water prices, have been frequently analysed for agricultural systems in North America and Europe (Coyle, 1993; Gorddard, 2009; Villezca-Becerra and Shumway, 1992; Moore and Negri, 1992; Fezzi and Bateman, 2009). However, few analyses are known for countries undergoing a process of economic and institutional transformation where property rights might be less clearly defined. Furthermore, often implementation and the working of enforcement mechanisms differ from what is known in North America and Europe.

Agricultural economists often have favoured modelling crop production decisions in terms of acreage responses rather than output supplies (Coyle, 1993). The key argument is that acreage planted is essentially independent of many non-behavioural factors such as seed quality, harvesting intensity and weather conditions, and hence may provide a closer proxy to planned production than does observed output (Coyle, 1993; Arnade and Kelch, 2007).

Most previous area response studies have estimated response functions separately for individual crops using a Nerlovian framework of partial adjustment and adaptive expectations (Nerlove, 1956; Askari and Cummings, 1977). However, problems in econometric specification and estimation of Nerlove models have been widely discussed and a number of papers extend the Nerlove model or other acreage response models to a system of multiple crops. Krakar and Paddock (1985) and Bewley, et al. (1987) use a multinominal logit approach in studying the allocation of fixed resources between alternative uses. Coyle (1993) developed an econometric model of crop acreage demands (for Western Canada) conditional on total crop acreage and related separability and dynamic specifications to reduce the effects of multicollinearity in the system. Hussain et al. (1999) estimate changes in crop areas in response to changes in output prices in Australian broad-acre agriculture, based on a model as a set of acreage allocation decisions made simultaneously but at a number of hierarchical stages. More recently, Gorddard (2009) estimates an econometric model of Saskatchewan crop land-allocation behaviour and tests for joint production in the presence of a land constraint.

There are several studies investigating the effects of subsidies and pricing policies related to agricultural production on crop allocations (Zavaleta, 1987; Rosegrant et al., 1995) or water entitlements on producer behaviour (Moore and Negri, 1992). Nevertheless, the impact of water policies favouring selected crops and the policy's effect on acreage allocation to different crops has rarely been analysed. Land is always regarded as the most fundamental input in agricultural production. However, for the production of water-intensive crops in arid regions, land without irrigation water is almost valueless.

In this paper, we present a model estimating the interaction of the two crucial inputs in the agricultural production system: land and water. Specifically, we analyse the impact of a water allocation priority policy for a specific potato variety on farmers' decision on acreage allocation among crops. We use the case of an arid region in northwest China, where agricultural is the biggest consumer of water taking 88.1% of total water resources.[1] The policy change regarding water allocation has been caused by the entry of a potato processor in this region which is partly owned by the regional government. The potato processing company entered in 2008 and demands a specific variety of potatoes, called Atlantic potatoes, for processing into flakes and starch. In order to meet the growing demand for Atlantic potatoes, the local government assigned water allocation priority for Atlantic potato growing to stimulate its production in this area. The water allocation priority policy requires that in spite of the water scarcity in this region, a sufficient amount of irrigation water (i.e. the amount of water that is physically required for a crop's production) has to be reserved for irrigating Atlantic potatoes. The remaining quantity of irrigation water is then allocated among the other crops. However, the stimulation of producing a crop with relatively high water demands via institutional instruments conflicts with the insufficiency of irrigation water in northwest China. Moreover, the sensitivity to pests and diseases imposes other technical restrictions on potato production (Franke et al., 2011). All these factors raised concerns about the water allocation priority policy.

[1] Water Management Bureau of Minle County, Gansu Province, P.R. China (2007).

This study aims to analyse the effect of the water allocation priority policy on farmers' production decisions. We estimate the reaction of farmers to the introduction of the priority policy in their acreage allocation to various crops. The analysis uses a unique two-year panel data set of farmers' acreage decisions. This article contributes to the literature by analyzing the impact of a priority policy for one agricultural input used for a specific crop. Compared to standard partial equilibrium analyses, our study covers the whole cropping part of the farm household and includes indirect effects of the water priority policy on other crops than Atlantic potatoes.

The remainder of this article is organized as follows. The following section establishes, based on a theoretical framework, a set of conditional land demand functions which will be estimated econometrically. Next, we describe the study area and the data underlying the econometric analysis. Subsequently, in section 4, we present and discuss the econometric results. The final section summarizes the main results of the empirical analysis and provides some policy recommendations.

2. Conceptual framework

Farmer's decision of allocating total land to various crops can be modelled basically in three different ways (Arnberg and Hansen, 2012; Moore et al., 1994). Programming models, for instance used by Amir and Fisher (2000) to evaluate water policies in Israel, unfortunately, lack a theory-based behavioural model. Among the approaches based on neoclassical producer theory, two strands can be distinguished. Models assuming input jointness assign inputs to all crops. Such an approach does not allow for a specific analysis of substitution in input use between crops. Alternatively, Moore et al. (1994) assign all inputs except one quasi-fixed but allocatable input (e.g. land) to individual crops. That is, variable inputs are used non-joint. The latter approach has the advantage that interdependences across crops can be accounted for explicitly in the model. Here we follow the non-jointness approach.

Each farmer is assumed to behave rationally and risk-neutral. Initially each farmer has a fixed amount of irrigation water which can be allocated to the various crops. Water trade is permitted since 2002 in this area. However, the vast majority of farmers do not engage in. Accordingly, each farmer decides how much land to assign to the different crops based on an optimisation procedure. Here, we assume the farmer to minimise costs of producing a given level of outputs.

Assume a farmer operates in a near optimal situation before the introduction of the water priority policy. After the policy change, the farmer looks for a new optimal input allocation by minimising costs subject to the previous level of output. Thus, the intermediate-run decision is the choice of the crops to grow and their acreage. All crops relevant for our analysis have been assigned to four groups: grain crops, cash crops, regular potatoes and Atlantic potatoes. Contrary to other studies, e.g. Moore et al. (1994), the land allocation is variable. The resulting first-order conditions state that each input's value of the marginal product in each use should be equal to the respective input's price. Introducing a priority policy for one crop, here Atlantic potatoes, implies an indirect subsidy of the input water for a specific use and an indirect taxation of this input in alternative uses. To quantify this effect we analyse the allocation of land to the different outputs. That is, based on the optimisation, the farmer decides how much land to allocate to output y_j. The resulting conditional input demand function for land $x^\mathrm{A}{}_\mathrm{j}$ is a function of output yields, prices of variable inputs (**w**) and levels of quasi-fixed inputs (**z**):

$$x^\mathrm{A}{}_\mathrm{j} = f(y_\mathrm{j}, \mathbf{w}, \mathbf{z});\ \text{for } j = 1, \ldots, n$$

Dividing each equation by total area (x^A) returns conditional land demand as a system of land share equations and normalised exogenous variables:

$$s_\mathrm{j} = x^\mathrm{A}{}_\mathrm{j}/x^\mathrm{A} = f(y_\mathrm{j}^*, \mathbf{w}^*, \mathbf{z}^*);\ \text{for } j = 1, \ldots, n.$$

Choosing a flexible approximation to a set of possible functional forms, we are left with the quadratic and translog functional form. Due to zero observations for outputs and inputs a quadratic functional form seems the best choice. Therefore, the conditional input demand function derived from a quadratic cost function is:

$$s_j = \beta_0 + \Sigma_\mathrm{k}\, \beta_{Ak}\, w^*{}_k + \beta_{Aj}\, y^*{}_j + \Sigma_\mathrm{t}\, \beta_{At}\, z^*{}_t;\ \text{for } j = 1, \ldots, n..$$

Together the share functions represent a system of conditional demand functions. Therefore, the standard theoretical restrictions will apply: The crop specific constants should add up to unity, the cross-terms should be symmetric and the functions should be homogeneous of degree zero in prices.

We are especially interested in the effect of the water policy's change on the acreage allocation across outputs. It is expected that farmers increase the share of land allocated to Atlantic potatoes produced for the manufacturer resulting in a lower elasticity of land demand. All other crops are expected to show an increasing elasticity of land demand with respect to the price of water.

3. Research area and data collection

For this research, we use data that we collected via two surveys held in Minle County, Zhangye City, Gansu Province. These surveys were carried out in May 2008 and May 2010. The 2008 survey serves as a baseline survey to assess the situation before the entry of the potato processing company in Minle County and the related water policy change. The 2010 survey is used to assess the impact of the new water policy on farmers' decisions on acreage allocation among crops.

Zhangye City is an oasis located midstream of the Heihe River, an inland river that flows across Qinghai Province, Gansu Province and Inner Mongolia Autonomous Region. It originates from the Qilianshan Mountains in Qinghai province and ends in Juyanhai Lake in Inner Mongolia. In the midstream of the Heihe River watershed, the land is flat, sunshine is abundant, and annual precipitation is very low while the evaporation is high. But due to the availability of irrigation water from the Heihe River, the area has become a major grain and vegetables production base in Gansu province.

According to the MWR[2] (2004), Zhangye City is severely short of water resources, even though it uses up almost all the water of Heihe River. Only 50% of farmland is well irrigated, and much arable land has been abandoned due to water shortage. Agriculture accounts for approximately 95% of all water use and almost all water in the Heihe River is extracted for irrigation use. As a result, too little water flows into Juyanhai Lake, which dried out in 1992 and an area of 200 km^2 around the lake became desert (MWR, 2004; Zhang et al., 2009).

To deal with these problems, the Ministry of Water Resources initiated a pilot project called 'Building a Water-saving Society in Zhangye City' in 2002. This project, which is the first of its type in the country, was designed to save water through government investments in a water-saving irrigation system and in meters for water users and through establishing a system of water use rights (WUR) with tradable

[2] Ministry of Water Resources

water quotas. The first two measures decreased irrigation water use somewhat, but trading of WUR did not become popular (Zhang et al., 2009).

Minle County, one of the six counties in Zhangye City, is located between the foothills of the Qilian Mountains and the lower lying Hexi corridor. Its total cultivated land area equals 860,000 mu[3], with irrigated land constituting 67 %. Major crops in Minle County include barley, wheat, maize, sesame, rapeseed, garlic and potato. As rotation, farmers in Minle County regularly change plots devoted to different crops. Surface water is the major water resource for irrigated agriculture in the area. Due to the high costs of pumping water from the wells, the use of groundwater is less than 5 % of total water use in irrigated agriculture (Water Bureau of Minle County).

Agricultural land in Minle County is usually divided into three zones with different planting conditions and water requirements. Zone 1 has an elevation ranging from 1,600 to 2,000 meters. Precipitation in this zone is relatively scarce. Zone 2 is located between 2,000 and 2,200 meters, while Zone 3 has an elevation ranging from 2,200 to 2,600 meters. By far the largest zone is the second one, with 500,000 mu of cultivated land, followed by the first and third zones, with 190,000 and 170,000 mu respectively. Agricultural production in the first and second zones generally uses irrigation, while most agricultural production in the third zone is rain fed.

The water used for surface irrigation is stored in seven reservoirs in the Qilianshan Mountains. Each of these reservoirs serves its own irrigation area within Minle County. A county-level water management bureau (WMB) is responsible for the water allocation institutions within the region. Seven lower-level WMBs, one for each of the seven irrigation areas, arrange the water allocations to WUAs within their own irrigation area. WUAs are responsible for arranging the water allocation to households belonging to their own WUA. The households within each WUA are sub-divided into water user groups (WUGs), consisting of households having plots along the same channel. Since the plots of different households within a WUG are irrigated at the same time, households belonging to a WUG need to coordinate their planting decisions and water demands.

Irrigation is carried out by flooding adjacent farmland at the same time, organized from lowest to highest altitudes, with villages in the first zone receiving more

[3] 15 mu equals one hectare.

irrigation rounds (generally three) per year than the villages in the other two zones (generally one or two rounds). Standard water quantities per mu are assigned for each flooding, but these quantities are only realized in years of abundant rainfall. Water is allocated according to a quota system based on the size of the so-called WUR land of the farmers. Not all the irrigated land is classified as WUR land. Its size depends on the amount of labour provided by a village to the construction of the reservoir and other factors.

The household survey data used in this study were collected in May 2008 and May 2010 by staff and students from Gansu Academy of Social Sciences in Lanzhou, Gansu Agricultural University in Lanzhou, and Nanjing Agricultural University. The data cover information over the years 2007 and 2009 containing information about land use, crop production, use as well as prices of water and other inputs, WUA participation and land tenure. Household interviews were done in the same 21 villages were a similar household survey was held in May 2008 (see Wachong Castro et al., 2010 for a description of the sampling method). If possible, the same households in each village that were interviewed in 2008 were also interviewed in May 2010. In cases were the same household could not be found, it was replaced by another, randomly selected, household in the same village. This resulted in a panel dataset containing 265 households. Six households among them rented out their land to other households and were engaged in off-farm work, thus didn't grow any crops either in 2007 or in 2009. Additionally, households that had missing data on one or more variables used in the empirical analysis and the outliers[4] were excluded. Finally, the following empirical analysis uses a two-year panel dataset containing 248 observations (households).

In order to simplify the econometric model, we aggregate crops into four groups: grains (barley, wheat, sesame and maize), cash crops (rapeseed and garlic), Atlantic potatoes supplied to the processing company and regular potatoes (various local varieties).

4. Data analysis and results

[4] Here we define outliers as households with large changes (>50%) in area shares of any crops between the two years.

Total land per household remained almost constant between the two years.[5] That is, the introduction of the water priority policy had no effect on farmers' decision to remain in agriculture. However, the policy change in terms of water allocation is expected to affect the acreage allocation decision. The possibly changing intensity of other inputs' use might be affected by the water priority policy. For instance, rational behaviour suggests a reduced use of inputs when the marginal product decreases given constant input and output prices. Therefore, in crop-specific production functions, we apply area shares rather than absolute value of planting areas as the dependent variable.

Table 1 displays average area shares of the four output categories in 2007 and 2009 (first two columns) and their changes from 2007 to 2009 (last columns).

Table 1

Because the table presents only changes in the mean and might underrepresent changes in the tails of the distribution, Graph 1 displays the changes as Kernel Density estimates. Obviously, the overwhelming majority of farmers kept area shares rather constant. Cash crops and regular potatoes experienced on average a reduction. The reduction in area share is particularly remarkable for regular potatoes, highly probable due to an increase of the share of Atlantic potatoes.

Graph 1

In the following econometric model the acreage allocation will be explained by output levels, prices of variable inputs[6], levels of quasi-fixed inputs and factors besides agricultural inputs (e.g. human capital, managerial capabilities, household characteristics and farm characteristics). All equations include village dummies to control for regional effects. The definition of all explanatory variables is presented in Table 2.

[5] The total areas of arable land for each household on average are 15.4 mu and 15.3 mu in 2007 and 2009, respectively.

[6] There is little variation of prices of pesticide between the households. Therefore, we do not incorporate the pesticide price in the models.

Table 2

The system of land share equations is estimated in two specifications. First, we estimate two static systems for 2007 and 2009. Second, we estimate the system in first differences. The first estimates can be interpreted as presenting farmers' behaviour on average before and after the water priority policy's introduction. The second estimates explore more the change at farm level, by taking out unobserved farm-specific effects due to first differencing. Of course the second model will miss all time invariant explanatory variables like farmer's age as well as slope and fertility of land.

The following Table 3 presents the elasticities derived from the estimated coefficients.[7] The estimated coefficients are presented in the Appendix.

Table 3

The estimated elasticities indicate that crop-share responses to the changes in variable input prices vary between different crops. Clearly, acreage allocation to grains shows the least elastic response variable inputs' prices and fixed inputs. Similarly, output changes cause a more elastic change in land demand for grains. This result holds for the model in levels and for both years. One reason for this behaviour lies in the essential proportion of grains grown by farmers and the prominent role of grains in peoples' diet. Grains are not only planted for selling on markets, but also used for own food consumption. That is, grains form the most important element in farmer's acreage allocation and will be substituted less against other crops.

Generally, elasticities of variable inputs are rather small. One remarkable exception is the effect of water price changes in 2007 on acreage demand for cash crops and Atlantic potatoes. Surprisingly, the estimated elasticities are positive, indicating a larger allocation of land to cash crops and Atlantic potatoes in areas where water prices are higher. Estimation without village controls yields much higher

---

[7] The elasticities of the response of area shares of different crops to a change in prices of variable inputs and levels of quasi-fixed inputs are calculated as: $\varepsilon_i = \frac{w_i}{s} * \beta_i$

elasticities[8]. Therefore, regional variation in the water price across WUAs does not fully explain the higher reagibility of acreage allocation to cash crops and Atlantic potatoes with respect to water price compared to the other two categories. Area devoted to regular potatoes is predicted to be smaller in areas with a higher water price in the 2007 model. After the introduction of the water priority policy, estimated elasticites with respect to water drop markedly across all crops. Differences across crops disappear and all elasticities turn out to be positive but very small. Atlantic potatoes become less attractive; the estimated elasticity drops to 0.021. On the other hand, for regular potatoes the elasticity increases from -0.038 to 0.030 after the water policy change.

Regarding the other variable inputs, hired labour stands out for the two types of potatoes. Similarly, the price of seeds is predicted to cause a stronger reaction of acreage allocation to cash crops and Atlantic potatoes compared to the two other two crop categories. Surprisingly, the elasticity for Atlantic potatoes has a positive sign.

Turning to the quasi-fixed inputs reveals an interesting change of Atlantic potatoes' position. Whereas the area of cash crops and Atlantic potatoes increases with increased use of own labour before the policy change, it does so only for cash crops after the policy change. With respect to own and exchanged labour Atlantic potatoes behave like grains and regular potatoes after the policy change. With respect to machinery services there is no change in signs for Atlantic potatoes.

Consistent with theoretical expectations, the output elasticities are all positive. An increase in crop yields leads to an increase in the area share for each of the four categories of crops. For instance, in 2007, the area share of Atlantic potatoes is predicted to increase by 0.006 %, when the yield of Atlantic potatoes goes up by 1 %. After the introduction of the water priority policy, output elasticity becomes markedly larger for both types of potatoes.

The results of model 2 show that farmers in areas were water prices increased reduced their acreage allocation to cash crops, Atlantic potatoes and regular potatoes. On the contrary, area devoted to grains increased. This is reasonable because grains receive less amount of water compared to the other three categories of crops.

[8] Detailed results available from the authors upon request.

Furthermore, increase in wages for hired labour affects cash crops most. The same holds for the amount of own labour and machinery service.

5. Conclusions and policy recommendations

This article analyses the impact of a priority policy for one agricultural input used for a specific crop on farmers' acreage allocation to different crops. To accomplish this, we estimate a system of crop acreage demands conditional on output yields, prices of variable inputs and levels of quasi-fixed inputs. The analysis bases on a two-year farm household panel data from an arid region in Northwest China. Previous research on this subject has concentrated on the case studies in North America, where property rights are relatively well-defined. Our research provides an example for countries undergoing a process of economic and institutional transformation where property rights might be less clearly defined.

Our findings indicate that policies related to water allocation regulation have remarkable effects on farmers' acreage allocation to various crops. More specifically, elasticities calculated from the coefficients of the econometric models show that before the introduction of the priority policy land demand is more elastic with respect to the price of water, particularly for the preferential crop (i.e. Atlantic potatoes). The elasticity effects of the prices of other variable inputs are relatively low. After the priority policy was introduced, the acreage changes become less elastic to the changes of water price.

The assumption of plots having no quality differences and to be fully divisible poses a limitation to our conceptual framework. Adding crop rotation requirements is straightforward and has been demonstrated by Arnberg and Hansen (2012).

An important policy implication that emerges from our results is that priority policy for an agricultural input clearly affects factor allocation within households, thus creates imbalances in remuneration of fixed factors.

References:

Amir, I., Fisher, F.M., 2000. "Response of Near-optimal Agricultural Production to Water Policies". *Agricultural Systems* 64: 115-130.

Arnade, C., and Kelch, D., 2007. Estimation of area elasticities from a standard profit function. American Journal of Agricultural Economics 89, 727-737.

Arnberg, S., Hansen, L.G., 2012. "Short-run and long-run dynamics of farm land allocation: panel data evidence from Denmark". Agricultural Economics 43: 179-190.

Askari, H. and Cummings, J.T., 1977. Estimating agricultural supply response with the Nerlove model: a survey, International Economic Review 18, 257-292.

Bewley, R., Young, T. and Colman, D., 1987. A system approach to modelling supply equations in agriculture. Journal of Agricultural Economics 35, 151-166.

Coyle, B.T., 1993. On modelling systems of crop acreage demands. Journal of Agricultural and Resource Economics 18, 57-69.

Fezzi, C. and Bateman, I.J., 2009. Structural agricultural land use modelling. The 27th International Conference of the International Association of Agricultural Economists, Beijing, P.R. China. August 16-22, 2009.

Franke, A.C., Steyn, J.M., Ranger, K.S., and Haverkort, A.J., 2011. Developing environmental principles, criteria, indicators and norms for potato production in South Africa through field surveys and modelling. Agricultural Systems 104, 297-306.

Gorddard, R.J., 2009. Modeling profit-maximizing land-allocation behavior. Agricultural and Resource Economics. Davis, University of California. Ph.D.

Hussain, I., Liaw, A. and Hafi, A., 1999. Modeling crop area allocations in Australian broadacre agriculture. Combined 43rd Annual Australian and 6th Annual New Zealand Agricultural and Resource Economics Society Conference. Christchurch, New Zealand.

Krakar, E. and Paddock, B., 1985. A systems approach to estimating prairie crop acreage. Working paper 15/85. Marketing and Economics Branch. Agriculture Canada, Canada.

Moore, M.R. and Negri, D.H., 1992. A multicrop production model of irrigated agriculture, applied to water allocation policy of the Bureau of reclamation. Journal of Agricultural and Resource Economics 17, 29-43.

Moore, M.R., Gollehon, N.R., Carey, M.B., 1994. "Alternative Models of Input Allocation in Multicrop Systems: Irrigation Water in the Central Plains, United States". *Agricultural Economics* 11: 143-158.

MWR, 2004. Pilot experiences of establishing a water-saving society in China. Beijing, China Water Press (in Chinese).

Nerlove, M., 1956. Estimates of the elasticities of supply of selected agricultural commodities. Journal of Farm Economics 38, 496-509.

Rosegrant, M.W., Schleyer R.G. and Yadav, S.N., 1995. Water policy for efficient agricultural diversification: market-based approaches. Food Policy 20, 203-223.

Villezca-Becerra, P.A. and Shumway, C.R., 1992. Multiple-output production modelled with three functional forms. Journal of Agricultural and Resource Economics 17, 13-28.

Wachong Castro, V., Heerink, N., Shi, X. and Qu, W., 2010. Water Savings through off-farm employment? China Agricultural Economic Review 2, 167-184.

Zavaleta, L.R., 1987. Irrigation water policy effects on regional crop allocations in Peru. Agricultural Systems 24, 249-268.

Zhang, J., Zhang, F., Zhang, L., and Wang, W., 2009. Transaction costs in water markets in the Heihe River Basin in Northwest China. International Journal of Water: Resources Development 25, 95-105.

Appendix A:

Table A1

Table A2

Table A3

Appendix B (for review purposes)**:**

The farmer is assumed to minimise costs as a function of input prices **w** and quasi-fixed factors **z** subject to the produced level of output **y** before the policy change by adjusting the variable inputs **x**.

$$\min_{\mathbf{x}} c = \sum_{i=1}^{n} w_i x_i + \sum_{t=1}^{o} w_t z_t \qquad \text{s.t. } \bar{y} \leq y(\mathbf{x}, \mathbf{z})$$, for all *y*.

Solving this optimisation problem yields a short-run cost function. Using a quadratic functional form, the short-run cost function for a multi-output multi-input farm is:

$$c = \alpha_0 + \sum_{j}^{m} \beta_j y_j + \sum_{i}^{n} \beta_i w_i + \sum_{t}^{o} \beta_t z_t + \frac{1}{2}\sum_{j}^{m} \beta_{jj} y_j^2 + \frac{1}{2}\sum_{i}^{n} \beta_{ii} w_i^2 + \frac{1}{2}\sum_{t}^{o} \beta_{tt} z_t^2 + \sum_{j}^{m}\sum_{k}^{p} \beta_{jk} y_j y_k + \sum_{i}^{n}\sum_{k}^{p} \beta_{ik} w_i w_k + \sum_{t}^{o}\sum_{k}^{p} \beta_{tk} z_t z_k + \sum_{j}^{m}\sum_{i}^{n} \beta_{ij} y_j w_i + \sum_{j}^{m}\sum_{t}^{p} \beta_{jt} y_j z_t + \sum_{i}^{n}\sum_{t}^{p} \beta_{it} w_i z_t$$

, for all j ≠ k, i ≠ k, t ≠ k.

Applying Shephard's Lemma yields the conditional input demand function for land:

$$\frac{\partial c}{\partial w_A} = x_A = \beta_A + \beta_{AA} w_A + \sum_{k}^{p} \beta_{Ak} w_k + \sum_{j}^{m} \beta_{jA} y_j + \sum_{t}^{o} \beta_{At} z_t$$.

We divide both sides of the conditional input demand function by total land which gives the acreage allocation functions for the four crops. Due to missing data on land prices, the land market is still underdeveloped in China, we have no price of land.

The price elasticity can be derived from the estimated coefficients using the formula: $\varepsilon_i = \frac{w_i}{s} * \beta_i$.

Tables:

Table 1: Area shares and changes in area shares of crops

Crop	Area shares [%]		Changes in area shares 2007 – 2009 [percentage points]			
	2007	2009	Mean	Std. Dev.	Min	Max
Grains	80.6	83.1	2.53	12.3	-37.5	49.2
Cash crops	10.3	9.8	-0.478	9.62	-50	37.5
Atlantic potatoes	0.6	1.7	1.07	4.10	-13.6	15.4
Regular potatoes	8.5	5.4	-3.13	8.59	-43.0	32.3

Table 2: Definitions of explanatory variables

Variable	Definition	Unit
	Prices of variable inputs	
Hired labour (Pl)	Prices of hired labour[1]	Yuan/minute
Seeds (Ps)	Prices of seeds[2]	Yuan/gram
Chemical fertilizer (Pf)	Prices of chemical fertilizer[3]	Yuan/gram
Water (Pw)	Prices of irrigation water[4]	Yuan/m^3
	Levels of quasi-fixed inputs	
Labour (Lr)	Amount of own labour and exchanged labour per mu land	Days/mu
Machinery (M)	Amount of money spent on own and hired machinery service per mu land	Yuan/mu
	Output levels	
Grains	Yields of grains per mu land	Jin[9]/mu
Cash crops	Yields of cash crops per mu land	Jin/mu
Atlantic potatoes	Yields of Atlantic potatoes per mu land	Jin/mu
Regular potatoes	Yields of regular potatoes per mu land	Jin/mu
	Household characteristics	
Non-working	Share of non-working members in the household	%
Gender	Ratio of male labourers in the household	%
Age head	Age of the head of the household	Years
Education head	Years of education of the head of the household	Years
	Farm characteristics	
Slope	Ratio of land on slope	%
Fertility	Average fertility of the land: 3 means bad quality, 1 means good	
Village	Dummy variables for different villages	

Notes:

1. Arithmetic average: because for all the households in our sample, they used hired labour for only one specific crop.
2. Weighted average: for instance for grains, we use the share of cropping shares of wheat, barley, maize and sesame as the weight to calculate the average prices of seeds of grains.
3. Arithmetic average is applied.
4. Prices of irrigation water are consistent for different crops for a specific household.

[9] 1 jin=0.5 kg

Table 3: Estimated elasticities

	Grains	Cash crops	Atlantic potatoes	Regular potatoes
Model 1 - 2007				
Input elasticities				
Price of hired labour	0.005	0.017	-0.063	-0.046
Price of seeds	0.004	-0.027	0.025	-0.001
Price of fertilizer	-0.001	-0.003	-0.005	0.006
Price of water	-0.018	0.260	0.361	-0.038
Amount of own labour and exchanged labour	-0.023	0.191	0.262	-0.015
Expenditures on machinery services	0.008	-0.063	-0.402	0.017
Output elasticities				
Yields of grains	0.078			
Yields of cash crops		0.013		
Yields of Atlantic potatoes			0.006	
Yields of regular potatoes				0.029
Model 1 – 2009				
Input elasticities				
Price of hired labour	0.003	-0.023	0.015	-0.018
Price of seeds	0.003	0.040	-0.056	-0.006
Price of fertilizer	0.0004	-0.008	-0.012	0.003
Price of water	0.003	0.004	0.021	0.030
Amount of own labour and exchanged labour	-0.001	0.027	-0.010	-0.031
Expenditures on machinery services	0.012	-0.094	-0.064	0.010
Output elasticities				
Yields of grains	0.020			
Yields of cash crops		0.065		
Yields of Atlantic potatoes			0.386	
Yields of regular potatoes				0.370
Model 2 (first differences)				
Input elasticities				
Price of hired labour	0.046	0.131	-0.006	0.023
Price of seeds	-0.024	0.019	-0.005	-0.019
Price of fertilizer	-0.0003	-0.001	0.000	-0.0002
Price of water	0.007	-0.021	-0.005	-0.001
Amount of own labour and exchanged labour	0.023	0.248	0.008	-0.021
Expenditures on machinery services	0.011	0.152	-0.051	-0.017
Output elasticities				
Yields of grains	-0.094			
Yields of cash crops		0.249		
Yields of Atlantic potatoes			-0.111	
Yields of regular potatoes				0.019

Table A1: Results of regression analysis (**model 1 - 2007**)

	Grains	**Cash crops**	**Atlantic potatoes**	**Regular potatoes**
Prices of variable inputs				
Price of hired labour	21.0 (1.03)	9.83 (0.63)	-2.15 (-0.69)	-21.6 * (-1.70)
Price of seeds	25.2 ** (2.07)	-21.7 ** (-2.36)	1.19 (0.63)	-0.439 (-0.06)
Price of fertilizer	-30.4 (-0.32)	-17.5 (-0.24)	-1.49 (-0.10)	25.6 (0.43)
Price of water	-15.8 (-0.47)	29.4 (0.20)	2.45 (0.32)	-3.56 * (1.76)
Levels of quasi-fixed inputs				
Amount of own and exchanged labour	-0.185 (-1.42)	0.195 ** (1.98)	0.016 (0.78)	-0.013 (-0.16)
Expenditures on machinery service	0.013 (0.46)	-0.013 (-0.58)	-0.005 (-1.06)	0.003 (0.14)
Output levels				
Yields of grains	0.007 * (1.65)			
Yields of cash crops		0.004 *** (3.70)		
Yields of Atlantic potatoes			0.002 *** (16.05)	
Yields of regular potatoes				0.001*** (4.59)
Household characteristics				
Non-working	0.061 (1.37)	-0.004 (-0.13)	0.012 * (1.71)	-0.036 (-1.30)
Gender	-0.005 (-0.10)	-0.010 (-0.25)	-0.004 (-0.58)	0.003 (0.09)
Age head	0.086 (1.17)	-0.082 (-1.46)	0.016 (1.36)	-0.035 (-0.76)
Education head	0.133 (0.58)	0.026 (0.15)	-0.012 (-0.33)	-0.213 (-1.48)
Farm characteristics				
Slope	-0.039 (-1.02)	0.058 ** (2.01)	-0.008 (-1.30)	-0.012 (-0.50)
Fertility	-1.38 (-0.98)	-0.208 (-0.20)	0.114 (0.53)	1.32 (1.52)
Village 1	-62.0 *** (-12.12)	64.8 *** (16.97)	0.140 (0.18)	-2.10 (-0.66)
Village 2	-57.1 *** (-13.59)	56.1 *** (17.98)	0.345 (0.50)	-1.94 (-0.75)
Village 3	-48.4 *** (-11.06)	47.1 *** (13.96)	0.027 (0.04)	0.173 (0.06)
Village 4	-30.9 *** (-7.64)	8.41 *** (2.71)	0.296 (0.47)	18.8 *** (7.35)
Village 5	-6.16 (-1.46)	1.66 (0.52)	0.210 (0.32)	1.72 (0.65)
Village 6	-19.15 *** (-4.18)	1.35 (0.44)	-0.001 (-0.00)	13.0 *** (5.20)
Village 7	-1.67 (-0.38)	-0.269 (-0.08)	-0.539 (-0.80)	-0.422 (-0.16)
Village 8	-3.91 (-0.99)	-2.31 (-0.69)	0.298 (0.49)	-1.13 (-0.46)

Village 9	-29.7 *** (-6.65)	26.9 *** (7.86)	-0.258 (-0.37)	0.317 (0.11)
Village 10	-20.5 *** (-5.06)	0.551 (0.18)	0.479 (0.76)	14.1 *** (5.38)
Village 11	-5.54 (-1.26)	0.875 (0.26)	0.327 (0.48)	0.947 (0.34)
Village 12	-11.1 ** (-2.30)	0.644 (0.18)	0.265 (0.36)	8.05 *** (2.68)
Village 13	-6.02 (-1.49)	-0.284 (-0.09)	0.363 (0.58)	3.01 (1.17)
Village 14	-12.5 *** (-3.07)	5.42 * (1.76)	0.133 (0.21)	5.73 ** (2.25)
Village 15	0.338 (0.08)	-1.06 (-0.34)	0.078 (0.12)	-0.556 (-0.22)
Village 16	-19.5 *** (-4.17)	-0.151 (-0.04)	0.295 (0.42)	14.5 *** (5.01)
Village 17	-9.09 ** (-2.22)	0.247 (0.08)	2.9 *** (4.59)	3.58 (1.39)
Village 18	-15.6 *** (-2.94)	0.729 (0.18)	0.423 (0.52)	11.4 *** (3.40)
Village 19	-7.63 * (-1.65)	-0.453 (-0.13)	0.275 (0.39)	3.62 (1.26)
Village 20	3.60 (0.83)	-1.21 (-0.38)	0.213 (0.32)	-2.84 (-1.06)
Intercept	91.4 *** (9.44)	1.72 (0.26)	-1.13 (-0.84)	-3.44 (-0.63)
Number of observations	248	248	248	248
R^2	0.79	0.88	0.67	0.63

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses. Homogeneity restriction imposed before estimation.

Table A2: Results of regression analysis (**model 1 - 2009**)

	Grains	**Cash crops**	**Atlantic potatoes**	**Regular potatoes**
Prices of variable inputs				
Price of hired labour	12.9 (0.75)	-10.7 (-0.71)	1.22 (0.34)	-4.72 (-0.56)
Price of seeds	-32.2 (-0.53)	49.4 (0.94)	-11.9 (-0.93)	-4.10 (-0.14)
Price of fertilizer	16.5 (1.56)	-39.2 (-0.22)	-10.3 (-0.36)	7.11 *** (-2.53)
Price of water	2.80 (0.20)	0.463 (0.04)	0.369 (0.12)	1.71 (0.25)
Levels of quasi-fixed inputs				
Amount of own and exchanged labour	-0.007 (-0.08)	0.030 (0.37)	-0.002 (-0.09)	-0.019 (-0.42)
Expenditures on machinery service	0.019 (0.68)	-0.017 (-0.69)	-0.002 (-0.43)	0.001 (0.08)
Output levels				
Yields of grains	0.002 (0.40)			
Yields of cash crops		0.002 ** (2.01)		
Yields of Atlantic potatoes			0.001 *** (9.58)	
Yields of regular potatoes				0.001 *** (4.26)
Household characteristics				
Non-working	0.027 (0.55)	-0.034 (-0.79)	0.006 (0.61)	-0.001 (-0.02)
Gender	-0.018 (-0.33)	0.025 (0.54)	-0.015 (-1.34)	0.015 (0.59)
Age head	0.008 (0.10)	-0.014 (-0.21)	0.027 * (1.65)	-0.029 (-0.76)
Education head	0.146 (0.62)	-0.038 (-0.19)	-0.006 (-0.12)	-0.088 (-0.78)
Farm characteristics				
Slope	0.093 (1.46)	-0.055 (-1.01)	-0.036 *** (-2.67)	-0.014 (-0.45)
Fertility	0.572 (0.40)	0.244 (0.20)	-0.223 (-0.75)	0.169 (0.25)
Village 1	-74.3 *** (-12.70)	78.8 *** (16.52)	-0.053 (-0.05)	-2.10 (-0.80)
Village 2	-53.6 *** (-10.94)	57.0 *** (13.42)	-0.979 (-0.95)	-2.80 (-1.20)
Village 3	-46.8 *** (-9.80)	47.1 *** (11.34)	-1.04 (-1.03)	1.14 (0.50)
Village 4	-10.1 ** (-2.25)	4.50 (1.13)	0.277 (0.29)	3.50 (1.63)
Village 5	-0.065 (-0.01)	-0.812 (-0.20)	-0.332 (-0.34)	-0.912 (-0.41)
Village 6	-11.0 *** (-2.59)	0.983 (0.25)	-0.908 (-1.00)	8.09 *** (3.90)
Village 7	3.43 (0.73)	-0.077 (-0.02)	-0.720 (-0.73)	-1.93 (-0.87)
Village 8	0.584 (0.14)	-0.466 (-0.12)	0.238 (0.26)	-2.05 (-1.00)
Village 9	-2.06 (-0.44)	1.84 (0.45)	-0.704 (-0.71)	1.54 (0.69)

Village 10	-3.84 (-0.86)	-0.401 (-0.10)	-0.835 (-0.87)	4.63 ** (2.12)
Village 11	-0.685 (-0.15)	-0.336 (-0.08)	-0.233 (-0.23)	-0.077 (-0.03)
Village 12	0.124 (0.02)	-0.550 (-0.13)	-1.01 (-0.93)	2.86 (1.19)
Village 13	0.772 (0.17)	-0.746 (-0.20)	-0.674 (-0.73)	0.473 (0.23)
Village 14	-9.25 ** (-2.01)	6.31 (1.59)	1.04 (1.07)	1.94 (0.88)
Village 15	1.42 (0.32)	0.154 (0.04)	-0.378 (-0.41)	-2.67 (-1.27)
Village 16	-17.1 *** (-3.39)	-0.786 (-0.18)	-0.042 (-0.04)	17.0 *** (6.99)
Village 17	-4.55 (-1.03)	0.818 (0.21)	5.43 *** (5.74)	-2.11 (-1.00)
Village 18	-9.86 * (-1.64)	-0.526 (-0.10)	-0.840 (-0.66)	9.54 *** (3.27)
Village 19	-4.98 (-0.92)	-1.29 (0.28)	2.11 * (1.90)	2.92 (1.16)
Village 20	1.01 (0.22)	0.933 (-0.23)	-0.247 (-0.25)	-0.548 (-0.25)
Intercept	88.8 *** (10.74)	1.09 (0.18)	0.802 (0.54)	3.42 (1.03)
Number of observations	248	248	248	248
R^2	0.79	0.85	0.61	0.53

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses. Homogeneity restriction imposed before estimation.

Table A3: Results of regression analysis (**model 2**)

	Grains	**Cash crops**	**Atlantic potatoes**	**Regular potatoes**
Prices of variable inputs				
Price of hired labour	38.7 *** (2.56)	-20.9 * (-1.80)	-2.31 (-0.65)	-24.1 ** (-2.40)
Price of seeds	12.1 (0.95)	1.85 (0.19)	1.12 (0.38)	-12.0 (-1.42)
Price of fertilizer	-55.1 (-0.69)	16.6 (0.07)	2.54 (-0.95)	35.7 (1.05)
Price of water	4.33 (0.32)	2.47 (0.24)	-1.35 (-0.43)	0.425 (0.05)
Levels of quasi-fixed inputs				
Amount of own and exchanged labour	-0.041 (-0.51)	0.083 (1.33)	-0.006 (-0.30)	-0.047 (-0.88)
Expenditures on machinery service	0.006 (0.26)	-0.016 (-0.94)	-0.012 ** (-2.35)	0.012 (0.85)
Output levels				
Yields of grains	0.004 (1.08)			
Yields of cash crops		0.002 *** (3.11)		
Yields of Atlantic potatoes			0.002 *** (15.82)	
Yields of regular potatoes				0.001 *** (5.09)
Household characteristics				
Non-working	-0.088 (-1.60)	0.087 ** (2.08)	-0.005 (0.43)	0.015 (0.42)
Gender	0.009 (0.19)	0.020 (0.52)	0.0002 (0.02)	-0.026 (-0.78)
Intercept	2.72 *** (3.24)	-0.507 (-0.81)	0.365 * (1.84)	-2.83 *** (-5.19)
Number of observations	248	248	248	248
R^2	0.05	0.07	0.53	0.15

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses. Homogeneity restriction imposed before estimation.

Figure 1: Kernel density estimates of changes (between 2007 and 2009) in land shares