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

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9
10 **Abstract:**

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

24 **Key words:** water scarcity, priority allocation, agricultural production

27 **1. Introduction**

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

39 Agricultural economists often have favoured modelling crop production decisions
40 in terms of acreage responses rather than output supplies (Coyle, 1993). The key
41 argument is that acreage planted is essentially independent of many non-behavioural
42 factors such as seed quality, harvesting intensity and weather conditions, and hence
43 may provide a closer proxy to planned production than does observed output (Coyle,
44 1993; Arnade and Kelch, 2007).

45 Most previous area response studies have estimated response functions separately
46 for individual crops using a Nerlovian framework of partial adjustment and adaptive
47 expectations (Nerlove, 1956; Askari and Cummings, 1977). However, problems in
48 econometric specification and estimation of Nerlove models have been widely
49 discussed and a number of papers extend the Nerlove model or other acreage response
50 models to a system of multiple crops. Krakar and Paddock (1985) and Bewley, et al.
51 (1987) use a multinomial logit approach in studying the allocation of fixed resources
52 between alternative uses. Coyle (1993) developed an econometric model of crop
53 acreage demands (for Western Canada) conditional on total crop acreage and related
54 separability and dynamic specifications to reduce the effects of multicollinearity in
55 the system. Hussain et al. (1999) estimate changes in crop areas in response to
56 changes in output prices in Australian broad-acre agriculture, based on a model as a
57 set of acreage allocation decisions made simultaneously but at a number of
58 hierarchical stages. More recently, Gorddard (2009) estimates an econometric model

59 of Saskatchewan crop land-allocation behaviour and tests for joint production in the
60 presence of a land constraint.

61 There are several studies investigating the effects of subsidies and pricing policies
62 related to agricultural production on crop allocations (Zavaleta, 1987; Rosegrant et al.,
63 1995) or water entitlements on producer behaviour (Moore and Negri, 1992).
64 Nevertheless, the impact of water policies favouring selected crops and the policy's
65 effect on acreage allocation to different crops has rarely been analysed. Land is
66 always regarded as the most fundamental input in agricultural production. However,
67 for the production of water-intensive crops in arid regions, land without irrigation
68 water is almost valueless.

69 In this paper, we present a model estimating the interaction of the two crucial
70 inputs in the agricultural production system: land and water. Specifically, we analyse
71 the impact of a water allocation priority policy for a specific potato variety on
72 farmers' decision on acreage allocation among crops. We use the case of an arid
73 region in northwest China, where agricultural is the biggest consumer of water taking
74 88.1% of total water resources.¹ The policy change regarding water allocation has
75 been caused by the entry of a potato processor in this region which is partly owned by
76 the regional government. The potato processing company entered in 2008 and
77 demands a specific variety of potatoes, called Atlantic potatoes, for processing into
78 flakes and starch. In order to meet the growing demand for Atlantic potatoes, the local
79 government assigned water allocation priority for Atlantic potato growing to stimulate
80 its production in this area. The water allocation priority policy requires that in spite of
81 the water scarcity in this region, a sufficient amount of irrigation water (i.e. the
82 amount of water that is physically required for a crop's production) has to be reserved
83 for irrigating Atlantic potatoes. The remaining quantity of irrigation water is then
84 allocated among the other crops. However, the stimulation of producing a crop with
85 relatively high water demands via institutional instruments conflicts with the
86 insufficiency of irrigation water in northwest China. Moreover, the sensitivity to pests
87 and diseases imposes other technical restrictions on potato production (Franke et al.,
88 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).

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

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

103

104 **2. Conceptual framework**

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

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

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

$$137 \quad x_j^A = f(y_j, \mathbf{w}, \mathbf{z}); \text{ for } j = 1, \dots, n$$

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

$$140 \quad s_j = x_j^A/x^A = f(y_j^*, \mathbf{w}^*, \mathbf{z}^*); \text{ for } j = 1, \dots, n.$$

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

$$145 \quad s_j = \beta_0 + \sum_k \beta_{Ak} w_k^* + \beta_{Aj} y_j^* + \sum_t \beta_{At} z_t^*; \text{ for } j = 1, \dots, n..$$

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

150 We are especially interested in the effect of the water policy's change on the
 151 acreage allocation across outputs. It is expected that farmers increase the share of land
 152 allocated to Atlantic potatoes produced for the manufacturer resulting in a lower

153 elasticity of land demand. All other crops are expected to show an increasing elasticity
154 of land demand with respect to the price of water.

155

156 **3. Research area and data collection**

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

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

171 According to the MWR² (2004), Zhangye City is severely short of water
172 resources, even though it uses up almost all the water of Heihe River. Only 50% of
173 farmland is well irrigated, and much arable land has been abandoned due to water
174 shortage. Agriculture accounts for approximately 95% of all water use and almost all
175 water in the Heihe River is extracted for irrigation use. As a result, too little water
176 flows into Juyanhai Lake, which dried out in 1992 and an area of 200 km² around the
177 lake became desert (MWR, 2004; Zhang et al., 2009).

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

² Ministry of Water Resources

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

185 Minle County, one of the six counties in Zhangye City, is located between the
186 foothills of the Qilian Mountains and the lower lying Hexi corridor. Its total cultivated
187 land area equals 860,000 mu³, with irrigated land constituting 67 %. Major crops in
188 Minle County include barley, wheat, maize, sesame, rapeseed, garlic and potato. As
189 rotation, farmers in Minle County regularly change plots devoted to different crops.
190 Surface water is the major water resource for irrigated agriculture in the area. Due to
191 the high costs of pumping water from the wells, the use of groundwater is less than
192 5 % of total water use in irrigated agriculture (Water Bureau of Minle County).

193 Agricultural land in Minle County is usually divided into three zones with
194 different planting conditions and water requirements. Zone 1 has an elevation ranging
195 from 1,600 to 2,000 meters. Precipitation in this zone is relatively scarce. Zone 2 is
196 located between 2,000 and 2,200 meters, while Zone 3 has an elevation ranging from
197 2,200 to 2,600 meters. By far the largest zone is the second one, with 500,000 mu of
198 cultivated land, followed by the first and third zones, with 190,000 and 170,000 mu
199 respectively. Agricultural production in the first and second zones generally uses
200 irrigation, while most agricultural production in the third zone is rain fed.

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

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

³ 15 mu equals one hectare.

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

221 The household survey data used in this study were collected in May 2008 and
222 May 2010 by staff and students from Gansu Academy of Social Sciences in Lanzhou,
223 Gansu Agricultural University in Lanzhou, and Nanjing Agricultural University. The
224 data cover information over the years 2007 and 2009 containing information about
225 land use, crop production, use as well as prices of water and other inputs, WUA
226 participation and land tenure. Household interviews were done in the same 21 villages
227 where a similar household survey was held in May 2008 (see Wachong Castro et al.,
228 2010 for a description of the sampling method). If possible, the same households in
229 each village that were interviewed in 2008 were also interviewed in May 2010. In
230 cases where the same household could not be found, it was replaced by another,
231 randomly selected, household in the same village. This resulted in a panel dataset
232 containing 265 households. Six households among them rented out their land to other
233 households and were engaged in off-farm work, thus didn't grow any crops either in
234 2007 or in 2009. Additionally, households that had missing data on one or more
235 variables used in the empirical analysis and the outliers⁴ were excluded. Finally, the
236 following empirical analysis uses a two-year panel dataset containing 248
237 observations (households).

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

242

243 **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.

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

253 Table 1 displays average area shares of the four output categories in 2007 and
254 2009 (first two columns) and their changes from 2007 to 2009 (last columns).

255 Table 1

256

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

263 Graph 1

264

265 In the following econometric model the acreage allocation will be explained by
266 output levels, prices of variable inputs⁶, levels of quasi-fixed inputs and factors
267 besides agricultural inputs (e.g. human capital, managerial capabilities, household
268 characteristics and farm characteristics). All equations include village dummies to
269 control for regional effects. The definition of all explanatory variables is presented in
270 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.

271

Table 2

272

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

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

282

Table 3

283

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

293 Generally, elasticities of variable inputs are rather small. One remarkable
294 exception is the effect of water price changes in 2007 on acreage demand for cash
295 crops and Atlantic potatoes. Surprisingly, the estimated elasticities are positive,
296 indicating a larger allocation of land to cash crops and Atlantic potatoes in areas
297 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: $\epsilon_i = \frac{w_i}{s} * \beta_i$

298 elasticities⁸. Therefore, regional variation in the water price across WUAs does not
299 fully explain the higher reability of acreage allocation to cash crops and Atlantic
300 potatoes with respect to water price compared to the other two categories. Area
301 devoted to regular potatoes is predicted to be smaller in areas with a higher water
302 price in the 2007 model. After the introduction of the water priority policy, estimated
303 elasticities with respect to water drop markedly across all crops. Differences across
304 crops disappear and all elasticities turn out to be positive but very small. Atlantic
305 potatoes become less attractive; the estimated elasticity drops to 0.021. On the other
306 hand, for regular potatoes the elasticity increases from -0.038 to 0.030 after the water
307 policy change.

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

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

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

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

⁸ Detailed results available from the authors upon request.

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

330

331 **5. Conclusions and policy recommendations**

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

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

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

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

355

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406

407

408

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410

411

Appendix A:

412

Table A1

413

414

Table A2

415

416

Table A3

Appendix B (for review purposes):

417

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

$$421 \min_{\mathbf{x}} c = \sum_{i=1}^n w_i x_i + \sum_{t=1}^o w_t z_t \quad \text{s.t. } \bar{y} \leq y(\mathbf{x}, \mathbf{z}), \quad \text{for all } y.$$

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

$$\begin{aligned} c = & \alpha_0 + \sum_j^m \beta_j y_j + \sum_i^n \beta_i w_i + \sum_t^o \beta_t z_t + \frac{1}{2} \sum_j^m \beta_{jj} y_j^2 \\ & + \frac{1}{2} \sum_i^n \beta_{ii} w_i^2 + \frac{1}{2} \sum_t^o \beta_{tt} z_t^2 + \sum_j^m \sum_k^p \beta_{jk} y_j y_k + \sum_i^n \sum_k^p \beta_{ik} w_i w_k \\ & + \sum_t^o \sum_k^p \beta_{tk} z_t z_k + \sum_j^m \sum_i^n \beta_{ij} y_j w_i + \sum_j^m \sum_t^o \beta_{jt} y_j z_t + \sum_i^n \sum_t^o \beta_{it} w_i z_t \end{aligned}$$

425
 426 , for all $j \neq k, i \neq k, t \neq k$.

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

$$429 \frac{\partial c}{\partial w_A} = x_A = \beta_A + \beta_{AA} w_A + \sum_k^p \beta_{Ak} w_k + \sum_j^m \beta_{jA} y_j + \sum_t^o \beta_{At} z_t$$

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

433 The price elasticity can be derived from the estimated coefficients using the

$$434 \text{ formula: } \varepsilon_i = \frac{w_i}{s} * \beta_i$$

435

436 **Tables:**437 **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

438

439

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	

441 Notes:

442 1. Arithmetic average: because for all the households in our sample, they used hired labour for only
443 one specific crop.444 2. Weighted average: for instance for grains, we use the share of cropping shares of wheat, barley,
445 maize and sesame as the weight to calculate the average prices of seeds of grains.

446 3. Arithmetic average is applied.

447 4. Prices of irrigation water are consistent for different crops for a specific household.

448

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

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

457
458

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

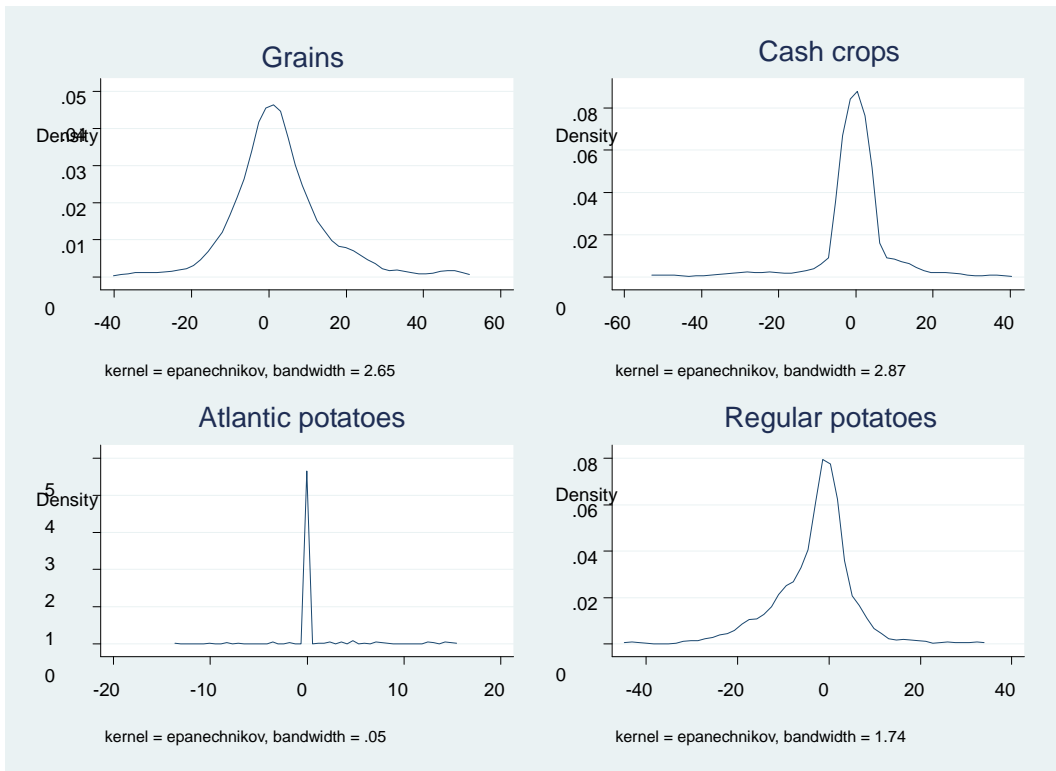
460 Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True
461 parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses.
462 Homogeneity restriction imposed before estimation.
463

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

465 Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True
466 parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses.
467 Homogeneity restriction imposed before estimation.
468

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



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