Environment and agriculture: the puzzle of organic farming

Huanxiu Guo* Sébastien Marchand†

CERDI, University of Auvergne

First draft ; do not quote

Abstract

While many studies demonstrate that organic farming has produced more than conventional farming in developing countries, the input of external organic nutrient is also increasing rapidly which pose a serious environmental concern. This case study attempts to re–evaluate the performance of organic farming on basis of environmental efficiency under the framework of stochastic frontier analysis. A plot level panel data is served to calculate the environmental efficiency across organic and conventional plots under small scale paddy rice production in southern China. Our two–stages analysis reveals that organic farming is more efficient only when the external nutrient input is on low level. Whilst farmers tend to increase the nutrient input when organic project was scaling up, it caused a significant loss of environmental efficiency for organic farming. With this observation, we claim that more prudence and institutional support is needed to maintain the sustainability of organic farming in full expansion.

Keywords: Organic farming, Social effect, Environmental efficiency, Farmer association, China.

JEL codes: Q12, Q57, R15, O53, D71.

---

*Ph.D candidate in Development Economics. Contact: `huanxiu.guo@u-clermont1.fr`, Tel: (+33)4 73 17 74 47.

†Corresponding author: Ph.D in Development Economics. Contact: Sebastien.Marchand@u-clermont1.fr, Tel: (+33)4 73 17 74 47.

1 Introduction

Regarded as a paradigm of sustainable development, organic farming has experienced a rapid growth in developing countries (e.g., Argentina, Brazil, China and India) as well as in developed countries during the past decades (Willer et al., 2009). If the major institutes of the world such as FAO, IFAD and the World Bank have firmly promoted organic agriculture on a global scale (F.A.O, 2002; Damiani, 2002; Bank, 2009), it's because organic farming demonstrated outstanding environmental and social benefits compared to modern conventional agriculture. For instance, according to numerous experience and reports form developed countries as well as developing countries, organic agriculture can reduce underground water pollution due to excessive chemical fertilizer and pesticide residues; improve the soil quality with rich soil organic matter and enhance self-reliance of agro–ecosystem as well as biodiversity (Pretty and Hine, 2001; Greene, 2009). While for the social aspect, high price premium of organic produce derived from increasing demand in Europe and US can help to reduce the rural poverty in developing countries (Bank, 2005; Twarog, 2006; Kilcher, 2007; Hine et al., 2008).

However, in spite of its promising outlooks, few governments adopted operational policy to convert modern conventional agriculture to organic agriculture on large scale. Doubts and critics of organic agriculture persist and focus on its productivity and the sufficient quantity of organic nutrients supply (Badgley et al., 2007; Avery, 1998; Connor, 2008). Moreover, an often neglected aspect relates to the pollution of organic nutrients. From an environmental point of view, it does not matter whether the nutrients come from inorganic or organic sources. The excessive use of nutrients from both sources will generate negative environmental effects, i.e., the leaching of nitrates from organic manure and the accumulation of heavy metals in soil following the application of Bordeaux mixture. In fact, ammonia volatilization is mainly caused by animal manure rather than by chemical Nitrogen (N) fertilizers (Pretty, 1995; Kirchmann et al., 1998). So even organic agriculture can achieve a superior productivity, if at the expense of more external organic nutrient, its sustainability is still questionable.

Therefore, it seems to be more accurate to evaluate the performance of organic agriculture on basis of environmental efficiency. The real question should be: can farmer in organic agriculture optimize the use of external nutrients to achieve the same productivity as modern conventional agriculture? In literature of efficiency study, Reinhard et al. (1999) has developed a methodological framework to calculate environmental efficiency using the stochastic frontier analysis, and this approach has provided useful insights into the environmental performance of Dutch dairy farming (Reinhard et al., 1999; Reinhard and Thijssen, 2000). In this case study, we apply this approach to the small-scale rice production in a Chinese village under the NGO led organic rice project. We focus on the use of Nitrogen fertilizer (from both organic and inorganic source), because it is the most important nutrient for the paddy rice production, while it is also the most important pollutant to underground water and air from agricultural production (Zhu and Chen, 2002).

The plot level panel data used in this study derived from an in-depth household survey conducted by one of the authors during 2010. In collaboration with a local agronomist, we have precise information about the external nutrient input for the rice production, as well as other conventional inputs and reliable yield data from the farmers' self report. With this abundant information in hands, we could calculate in first step the environmental efficiency across all farmers in the village, for both organic and conventional farming. In the second step, we take a look into the variation of environmental efficiency between organic farming and conventional farming over time and on different level of nutrient input. In contrary to common wisdom, our study demonstrates that organic farming does not necessarily make better use of Nitrogen than conventional farming for rice production. Especially on high nutrient input level, effect of organic farming is non significant even negative in terms of environmental efficiency. Besides, our findings also highlight significant loss of environmental efficiency for organic farming in process of scaling up so we claim more prudence and effective institutional support facing the rapid growth of organic agriculture in developing country.

The remainder of this paper is organized as follow. Section 2 presents the organic rice project in the village and production change induced by the project. Section 3 gives details on the data and Section 4 describes our methodological framework and empirical method. Then Section 5 discusses the main results and Section 6 concludes.

2 An example of organic farming in a small Chinese village

Initiated by export orientation, Organic Agriculture has now turned to be a rural sustainable development strategy in China. Vibrant organic communities can be observed in rural China along with the social movement of New Rural Reconstruction since 2003. Besides the single company led model, more diverse models such as farmers' co-op, farmer-participatory development and Community Supported Agriculture (CSA) have emerged to develop the organic agriculture recently (Day, 2008; Jia'en and Jie, 2011). In this study, we focus on one of these innovative models in southern China.

Sancha village (109.01E/22.73N) is a small and poor village in Guangxi province[1]. Given its abundant water resource and tropical climate, paddy rice is one of the most important crops in this region. The paddy rice production in Sancha village remains traditional, e.g., 2 crops seasons per year, rain fed culture, cattle tillage, cow dung fertilizer . . . Since 1980s', machinery and modern chemical inputs have been democratized in the region. For its undeveloped nature,

---

[1] The population of Sancha village is about 700 villagers, with an average income about 1700 yuan per capita in 2007.

Sancha village didn't cope with the progress of "green revolution". The average chemical fertilizer application level in the village is about 16.76 kg/mu[2] which is much lower than the provincial level of 26.24 kg/mu[3]. The well preserved natural environment constituted the main advantage for organic farming development.

In 2005, the organic rice project has been introduced by PCD to Sancha village with aim to convert farmers from conventional farming to organic farming[4]. The project has begun in form of experimentations within a small group of farmers. Whilst the NGO provided technical guidance and market support (CSA) to encourage the conversion form conventional farming to organic farming, farmers decided the quantity of inputs to use according to their own observation and took responsibility for their yield. By means of these farmer participatory experimentations, farmers have found their own nutrient formula to substitute the conventional chemical fertilizer by self-produced compost and leguminous cover crop[5]. On the aspect of pest control, organic farmers adopted the integrated rice–duck culture and make use of traditional medical plant, which has been proven effective in preventing certain pest. In order to coordinate the project and monitor farmers' organic production, a farmers association has been founded with help of NGO. More essentially, the routine regulation by farmers association has guaranteed the respect of OA standards and the quality of organic produce, and provided the high cost of OA certification which is not affordable for poor farmers in Sancha village.

Over 3 years' experimentation, the project entered into the novel phase of scaling up. By chance of the local government's policy intervention of rural community construction, farmers had access to more information about the project of organic farming. An acceleration of conversion has been observed since 2009. At the end of 2009, 73 percent of farmers in the village have decided to undertake organic experimentation on their paddies, that's to say convert partially to organic farming. During the infield observation, we noted that although organic farming has been universally accepted in the village mainly for its high price premium, farmers still have doubts on its productivity, especially for new converted farmers[6]. In addition to constraint of labors and organic nutrient, only 29 percent of the paddies have been converted to organic farming.

Sancha village is regarded as one paradigm of "New Socialist Countryside" for its successful organic farming development. It is suitable for the comparative study from which we can draw a general picture for organic farming in poor rural place. Table 1 gives details according to major indicators: productivity, Nitrogen (N) input and N balance in soil. We can also take

---

[2] It is calculated from the Data of household survey conducted by author.

[3] Data comes from China statistical year book.

[4] PCD Partnerships for Community Development, is a NGO based in Hong Kong. More information about this NGO can be found on their site: `http://www.pcd.org.hk/eng/index.html`.

[5] Compost is produced by farmers with fish powder, bone powder, tea bran, peanut bran, Biogas slurry ...

[6] Through the CSA network, the price of organic rice is two times superior than the conventional rice sold at local market.

a glance at the trends of these performances during 5 consecutive crops seasons (2008-2010)[7]. From the first column, we note that organic farming has successfully coped with conventional farming in terms of productivity. There is no significant difference between organic farming and conventional farming during 5 crops seasons. While in terms of the external N input, organic farming didn't really improve the situation. Especially in the period of scaling up (since season 3), farmers trended to use more and more external N input. This phenomenon is quite normal according to the farmers association. Because new converted farmers had less experience and confidence, they would generally apply more compost or animal manure for fear of yield loss from conversion. Since they didn't use chemical fertilizer and pesticide, the OA standard was respected as well. To evaluate the environmental impact, we then use the soil surface nutrient budget to calculate the N balance for both organic farming and conventional farming[8]. A persistent deficit in nutrient budgets might indicate mining of soil nutrients, whilst a persistent surplus might indicate potential environmental pollution (OECD, 2001). Not surprisingly, both type of farming displayed a persistent N surplus, which highlights the necessity of N input optimization. And once again, the N balance indicates a significant loss of environmental performance for organic farming during the period of scaling up.

Table 1: Organic farming vs. conventional farming in Sancha village

	Yield (kg/mu)			N input (kg/mu)			N balance (kg/mu)		
	Organic	Conv	dif	Organic	Conv	dif	Organic	Conv	dif
season 1	360.6(84.1)	363.3(94.1)	ns	13.3(3.2)	15.0(4.0)	**	5.0(3.7)	6.7(3.4)	**
season 2	313.7(92.6)	323.7(92.8)	ns	12.1(3.3)	12.9(3.8)	ns	4.9(3.7)	5.5(3.3)	ns
season 3	339.0(91.8)	363.0(97.5)	*	15.4(4.5)	14.9(3.8)	ns	7.6(4.8)	6.6(3.2)	*
season 4	301.9(86.8)	316.5(102.8)	ns	14.4(3.9)	12.5(3.7)	***	7.5(4.1)	5.2(3.1)	***
season 5	363.5(72.8)	362.5(90.3)	ns	15.2(3.8)	14.6(3.6)	ns	6.8(4.1)	6.3(3.1)	ns

Notes: Data calculated from author's survey and scientific experimentation data provided by infield agronomist of PCD. The mean value is presented with standard deviation in parentheses. *** statistical significance at 0.1%, ** statistical significance at 1%, * statistical significance at 0.5%. "ns" means non significant.

To summarize, during 5 consecutive crops seasons, organic farmers of Sancha village have achieved a satisfactory productivity by substituting the chemical fertilizers with self-produced organic fertilizers. This is a big success from an economic point of view. However the environmental cost is till high in terms of external N input when scaling up. Therefore, we will need a more sophisticate indicator on basis of N efficiency to re–evaluate the performance of organic

---

[7] Seasons 1–2, 3–4 and 5 cover alternatively 2008, 2009 and 2010.

[8] The soil surface N balance is calculated as the difference between the total quantity of nitrogen inputs entering, and the quantity of nitrogen leaving, the soil over one season. Quantified inputs included chemical fertilizers (e.g. compound fertilizer, Urea Fertilizer); organic fertilizer (e.g. compost); organic inputs (e.g. animal manures, straw). Outputs were yield of raw rice.

farming. For this purpose, we will then present the indicator of environmental efficiency using the stochastic frontier analysis in the following section.

3 Analytical model and empirical method

The link between organic farming and environmental efficiency (EE) in agriculture is analysed through a two–steps approach. Environmental efficiency is first defined in terms of technical efficiency which is calculated from a stochastic production frontier model. In the second step, the estimated environmental efficiency is regressed on organic farming.

3.1 calculate environmental efficiency from a stochastic production frontier model

To figure out the effect of organic farming on environmental efficiency, we need first to compute this efficiency. The way of doing that is to introduce environmental variables into a traditional production function in order to derive environmental efficiency from adjustments of conventional measures of technical efficiency (TE).

TE is first derived from a production frontier under the hypothesis that a non-optimal use of production factors by agricultural farmers, i.e., an X-inefficiency (Leibenstein, 1966), is the effect of labor and credit constraints. This way, assuming that a farmer i uses traditional inputs X to produce a single or a multiple conventional output Y, a production function can be written to represent a particular technology: $Y_i = f(x_i)$, where $f(x_i)$ is a production frontier. On the frontier, the farmer produces the maximum output for a given set of traditional inputs or uses the minimum set of traditional inputs to produce a given level of output. In standard microeconomic theory, there is no inefficiency in the economy, implying that all production functions are optimal and all firms produce at the frontier. But if markets are imperfect, farmers can be pulled beneath the production frontier.

Moreover, some environmentally detrimental, i.e., undesirable, variables can be introduced in the function production[9]. This way, a farmer need to maximize his conventional desirable outputs with the set of undesirable environmental inputs as well as its conventional inputs (x).

In this context, we follow Reinhard et al. (1999) by stating environmental efficiency (EE) as the ratio of minimum feasible to observed use of multiple environmentally detrimental inputs, conditional on observed levels of output and the conventional inputs[10]. This can be formulated

---

[9] We consider in this paper that environmentally detrimental variables are undesirables inputs. However, they can be treated as undesirable outputs. For instance, see Cuesta et al. (2009).

[10] Environmental efficiency is thus an input–oriented measure (more conventional output with the same set of environmental detrimental inputs) which is no more than a single-factor measure of the technical efficiency of the environmentally detrimental input.

by the following non–radial input–oriented measure

$$EE_i(x, y) = [\min \theta : F(x_k^i, \theta Z_l^i) \geq y^i], \tag{1}$$

where the variable y^i is the observed output for farmer i, produced using X^i of the conventional input and Z^i of the environmentally detrimental input. $F(.)$ is the best practise frontier with X and Z.

EE is then estimated under three auxiliary hypotheses. Firstly, (1) is applied to an econometric model (Kumbhakar and Lovell, 2000, p.64):

$$Y_{i,t} = F(X_{i,t}, Z_{i,t}; \beta).e^{-U_{i,t}}, \tag{2}$$

where $Y_{i,t}$ is a scalar of conventional output, $X_{i,t}$ is a vector of traditional inputs and $Z_{i,t}$ is a vector of environmental undesirable input used by farmers $i = 1, \ldots, N$ at time $t = 1, \ldots, T$. $F(X_{i,t}, Z_{i,t}; \beta)$ is the production frontier[11] and β is a vector of technology parameters to be estimated. U_i are non-negative unobservable random variables associated with technical efficiency that follow an arbitrary distribution[12]. Here, following Reinhard et al. (1999), technical efficiency is measured with an output orientation as the ratio of observed to maximum feasible output as follows

$$TE_{i,t}(x, y) = [\max \phi : \phi y_{i,t} \leq f(x_{i,t}, z_{i,t})]^{-1}, \tag{3}$$

where ϕ is the maximum output expansion with the set of inputs x_i.

Secondly, a stochastic production frontier is used so that the error term has two components: random shocks V_i (not attributed to the relationship between inputs and output) and an inefficiency term U_i (Aigner et al., 1977; Meeusen and van den Broeck, 1977). Eq. (2) becomes

$$Y_{i,t} = F(X_{i,t}, Z_{i,t}; \beta).e^{-U_{i,t}}.e^{V_{i,t}}, \tag{4}$$

where $V_{i,t}$ represent random shocks which are assumed to be independent and identically distributed random errors with a normal distribution of zero mean and unknown variance. Under that hypothesis, a farmer beneath the frontier is not totally inefficient because inefficiencies can also be the result of random shocks (such as climatic shocks).

Since TE_i is an output-oriented measure of technical efficiency, a measure of TE_i is:

$$TE_i = \frac{Prod_{obs}}{Prod_{max}} = \frac{f(X_i; \beta).e^{-U_i}.e^{V_i}}{f(X_i; \beta).e^{V_i}} = e^{-U_i}. \tag{5}$$

Environmental efficiency and technical efficiency are then estimated using the stochastic

---

[11] The production frontier has the traditional properties of monotonicity, continuity and concavity (Fuss and McFadden, 1978, p.226-227).

[12] It can be either a half-sided normal distribution or an exponential one.

frontier model given by (4) and (5).

Thirdly, the production function is modelled using a transcendental logarithmic ("translog") specification (Diewert, 1971). The translog specification is preferred to the Cobb–Douglas form because of its flexibility implying no restrictions on a coefficient's substitutability (factor substitutability is equal to one in the Cobb–Douglas case)[13].

In this case study, the general form of the traditional translog with three traditional inputs and one environmental detrimental input is as follows (Christensen et al., 1971)[14]:

$$\begin{aligned} ln(Y_{i,t}) = \beta_0 + \sum_{j=1}^{3} \beta_j ln(X_{ij,t}) + \beta_z ln(Z_{i,t}) + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \beta_{jk} ln(X_{ji,t}) ln(X_{ki,t}) \\ + \frac{1}{2}\sum_{j=1}^{3} \beta_{jz} ln(X_{ji,t}) ln(Z_{i,t}) + \frac{1}{2}\beta_{zz} ln(Z_{i,t})^2 - U_{i,t} + V_{i,t}, \end{aligned} \tag{6}$$

where $i = 1, \ldots, N$ are the farmer unit observations and $t = 1, \ldots, T$ are the number of periods; $j, k = 1, 2, \ldots, 3$ are the applied traditional inputs; $ln(Y_{i,t})$ is the logarithm of the output of farmer i; $ln(X_{ij,t})$ is the logarithm of the j^{th} traditional input applied of the i^{th} individual; $ln(Z_{i,t})$ is the logarithm of the environmental detrimental input applied of the i^{th} individual; and β_j, β_z, β_{jk}, β_{jz} and β_{zz} are parameters to be estimated[15]. The logarithm of the output of a technically efficient producer $Y_{i,t}^F$ with $X_{i,t}$ and $Z_{i,t}$ can be obtained by setting $U_{i,t} = 0$ in equation 6. However, the logarithm of the output of an environmentally efficient producer $Y_{i,t}$ with $X_{i,t}$ and $Z_{i,t}^F$ is obtained by replacing $Z_{i,t}$ and $Z_{i,t}^F$ and setting $U_{i,t} = 0$ in equation 6 as follows

$$\begin{aligned} ln(Y_{i,t}) = \beta_0 + \sum_{j=1}^{3} \beta_j ln(X_{ij,t}) + \beta_z ln(Z_{i,t}^F) + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \beta_{jk} ln(X_{ji,t}) ln(X_{ki,t}) \\ + \frac{1}{2}\sum_{j=1}^{3} \beta_{jz} ln(X_{ji,t}) ln(Z_{i,t}^F) + \frac{1}{2}\beta_{zz} ln(Z_{i,t}^F)^2 + V_{i,t}, \end{aligned} \tag{7}$$

The logarithm of th environmental efficiency ($lnEE_{i,t} = lnZ_{i,t}^F + lnZ_{i,t}$) can now be calculated by setting equations 6 and 7 equals as follows

---

[13] A likelihood ratio test (LR) was implemented in order to test the functional form of the production function. In all tests, restrictions can be rejected at a very low confidence level, so that the translog specification can be preferred. Details available upon request.

[14] We use a negative sign in order to show that the term $-U_{i,t}$ represents the difference between the best efficient farm (on the frontier) and the observed farm.

[15] Similarity conditions are imposed, i.e., $\beta_{jk} = \beta_{kj}$. Moreover, the production frontier requires monotonicity (first derivatives, i.e., elasticities between 0 and 1 with respect to all inputs) and concavity (negative second derivatives). These assumptions should be checked *a posteriori* by using the estimated parameters for each data point.

$$\frac{1}{2}\beta_{zz}[lnZ^F_{i,t}) - lnZ^F_{i,t}]^2 + (lnZ^F_{i,t}) - lnZ^F_{i,t})[\beta_z + \sum_{j=1}^{3}\beta_{jz}lnX_{ij,t} + \beta_{zz}lnZ_{i,t}] + U_{i,t} = 0, \tag{8}$$

when environmental efficiency, $lnEE_{i,t} = lnZ^F_{i,t} + lnZ_{i,t}$ is

$$\begin{aligned} &lnEE_{i,t} \\ &= \Bigg[-\left(\overbrace{\beta_z + \sum_{j=1}^{3}\beta_{jz}lnX_{ij,t} + \beta_{zz}lnZ_{i,t}}^{A}\right) \\ &\pm \left\{\left(\overbrace{\beta_z + \sum_{j=1}^{3}\beta_{jz}lnX_{ij,t} + \beta_{zz}lnZ_{i,t}}^{B}\right) - 2\beta_{zz}U_{i,t}\right\}^{0.5}\Bigg] / \beta_{zz} \end{aligned} \tag{9}$$

As mentioned by Reinhard et al. (1999), the output-oriented efficiency (eq. 5) is estimated econometrically whereas environmental efficiency (eq. 8) are calculated from parameter estimates (β_z and β_{zz}) and the estimated error component ($U_{i,t}$).

As we have mentioned, a technically efficient farm ($U_{i,t} = 0$) is necessarily environmentally efficient ($lnEE_{i,t} = 0$). Thus, the "$+\sqrt{}$" needs to be used[16].

The final empirical model estimated in the translog case is:

$$\begin{aligned} Output_{k,i,t} &= \beta_0 + \beta_1.Labor_{k,i,t} + \beta_2.Capital_{k,i,t} + \beta_3.Water_{k,i,t} + \beta_4.N_{k,i,t} \\ &+\beta_5.Labor^2_{k,i,t} + \cdots + \beta_9.Labor_{k,i,t} * Capital_{k,i,t} + \cdots + \sum_{j=1}^{5} Seasons + -U_{k,i,t} + V_{k,i,t}, \end{aligned} \tag{10}$$

which represents the relationship between the output and both traditional and environmental inputs of plot k for farmer i and where $Seasons$ is a dummy fixing each of the five crop seasons and $SEED$ is a coded variable for the type of species of the rice. The output is the yield from rice production, traditional inputs are the labor, capital and water, and the environmental input is N, external Nitrogen input (see Tables 2 and 4 for descriptive statistics, and Table 3 for description and definition variables).

Finally, the inefficiency term is allowed to be time–variant following the Battese–Coelli parametrization of time-effects (Battese and Coelli, 1992). This way, the maximum likelihood estimator is used to estimate the technical efficiency which is modeled as a truncated-normal

---

[16] The sign in front of the term B should be necessarily positive. This way, if $U_{i,t} = 0$, then $lnEE_{i,t} = 0$.

random variable multiplied by a specific function of time[17].

3.2 The estimation of organic farming on environmental efficiency

After having estimated environmental efficiency, we then assess the effect of organic farming on this efficiency. The design of the implementation of organic farming in our Chinese rural village allows us to figure out this issue through two different methods. In fact, the implementation of organic farming in our Chinese rural village was encouraged and scaled up after 2009 so that we try to understand if the performance of organic farming can be different before and after 2009. This way, we try first to figure out if the effect of organic farming on environmental efficiency can differ after 2009 as follows

$$EE_{k,i,t} = \alpha_0 + \alpha_1 Organic_{k,i,t} + \alpha_2 2009_{k,i,t} + \alpha_3 2009 * Organic_{k,i,t} + \sum_{j=1}^{9} \alpha_{jz} lnX_{k,i,t} + \varepsilon_{k,i,t}, \tag{11}$$

which represents the relationship between the environmental efficiency and organic farming of plot k for farmer i where $\varepsilon_{k,i,t}$ is the error term. The variable 2009 is a dummy with 1 if the season is in 2009 or after and 0 if the season is in 2008[18]. The variable $2009 * Organic$ is an interactive term which captures the effect of organic from 2009. $X_{k,i,t}$ is a matrix of explanatory variables which are the area, the geographical situation and the soil quality of the plot; the age, the sex and the level of education of the household head, and the seed and the level of external Nitrogen input (N) used on the plot. Moreover, to avoid endogenous issues of organic farming, two instrumental variables are used: the geographical distance from farmer's house to the plot in terms of minutes of walk (coded from 1 to 4) and the presence of pollution from chemical fertilizer application near the plot (1 for yes and 0 otherwise)[19]. For the instrumentation of the interactive variable, two other instruments are used and consist in the interaction between each IV of organic farming with the dummy 2009.

Second, we try to figure out the effect of organic farming on environmental efficiency along with the level of external Nitrogen input (N) used in the plot. The regression equation is as follows

$$EE_{k,i,t} = \gamma_0 + \gamma_1 . Organic_{k,i,t} + \gamma_{k,i,t} lnN + \sum_{j=1}^{8} \gamma_{jz} lnX_{k,i,t} + \sum_{j=1}^{5} Seasons \varepsilon_{k,i,t}, \tag{12}$$

---

[17] Estimations are made using Stata 10 and the command *xtfrontier*.

[18] Remember that there are five seasons from 2008 to the first semester of 2010.

[19] The geographical distance is a subjective evaluation provided by the farmer. See Table 3 for more information on the two instrumental variables.

which represents the relationship between the environmental efficiency and organic farming of plot k for farmer i, where $Seasons$ is a dummy fixing one of the five seasons and $\varepsilon_{k,i,t}$, the error term. $X_{k,i,t}$ is the same matrix of explanatory variables than in equation 11.

Equation 12 is then estimated on three different sub–sample along with the level of the log of external Nitrogen input. This variable is sampled in (1) a high sub–sample which represents the one third plots under which the N input is the most used (ln N > 3.42); (2) a low sub–sample for the one third plots under which the N input is the least used (ln N < 3.20); (3) a medium sub–sample for the one third remaining plots (ln N between 3.20 and 3.42). For each regression, the two same IV variables are used to avoid the problem of endogeneity of organic farming.

4 Data

The data we use in this study derived from an in–depth survey conducted by author in Sancha village. For purpose of comparative study, all active farmers in village were asked to select on random basis one organic plot and one conventional plot from all his plots and to give information of these 2 plots separately[20]. Information is collected for the past 5 consecutive crops seasons (from 2008 to 2010) with respect to output levels and input use on the plot. Socio–economic characteristics and plot characteristics are collected as well. Rice yield is expressed in terms of kg/mu. Data are collected for 4 productive inputs: labor, capital, Nitrogen input and water. Labour use is expressed as hours/mu. Capital use is measured as yuan/mu. For external Nitrogen input, we use the scientific experimentation data of Nitrogen content for each nutrient input in Sancha village provided by the infield agronomist to calculate the pure N input[21]. It is expressed in terms of kg/mu. While water use is difficult to measure, we have developed an index of water availability to serve as a proxy. Given the nature of rain fed culture, we think the water availability decides the water use in the village. Socio–economic characteristics are also collected for the survey sample. These characteristics include Age, sex and educational level of farmer. For the plot characteristics, we collected information about area, geographical situation, soil quality, geographical distance and presence of pollution spot nearby. These data are used in the analysis to identify important characteristics influencing environmental efficiency of organic farming. Table 2 gives descriptive statistics of our data base and detailed description of the variables can be found in Table 3.

---

[20] Farmers with no organic plots were asked to give information about 2 conventional plots randomly and similarly, for farmers with no conventional plots.

[21] The nutrient input used in Sancha village include : chemical fertilizer (compound fertilizer, Urea Fertilizer); organic fertilizer(compost); organic input(straw, cow dung, chicken manure, pig manure).

Table 2: Descriptive statistics by type of farming

	Total(1,012)		Organic Plot(345)		Conventional Plot(667)		Test of equality
	Mean	Sd	Mean	Sd	Mean	Sd	P-value
Outputs and inputs							
Yield (kg/mu)	342.16	94.46	336.49	88.15	345.09	97.5	0.17
Labor (h/mu)	129.81	54.01	156.33	55.29	116.09	47.92	0
N (kg/mu)	14.13	3.96	14.42	4.03	13.97	3.93	0.08
Capital (yuan/mu)	74.17	52.21	76.53	51.31	72.95	52.67	0.3
Water (0-2)	2.51	0.65	2.56	0.67	2.49	0.64	0.14
Household characteristics							
Age	54.59	12.59	53.42	12.47	55.19	12.62	0.03
Sex	0.61	0.49	0.68	0.47	0.57	0.5	0
Education	3.64	3.3	3.79	3.51	3.56	3.19	0.29
Plot characteristics							
Area (mu)	0.38	0.2	0.39	0.2	0.38	0.21	0.69
Geographical situation (0/1)	0.07	0.25	0.01	0.12	0.1	0.3	0
Soil quality (1-3)	2.33	0.77	2.68	0.58	2.15	0.79	0
Distance (1-4)	1.91	0.87	1.57	0.65	2.09	0.91	0
Pollution (1/0)	0.74	0.44	0.34	0.48	0.95	0.22	0

Note: For all tests of means, the null hypothesis is that the means are equal against a two–sided alternative. The confidence level is at 5%.

From this descriptive statistics, we remark that organic farming is more labor consumer than conventional farming. In addition to the age difference between organic farming and conventional farming, it is reasonable to identify the limited labor force as one of important constraints for organic farming development in rural place. Nevertheless, it seems that organic farming has absorbed more female labor than conventional farming. For other factors that may remark the organic farming, we note that most organic plots are well situated, good quality and less distant from farmers house. And finally, the presence of fertilizer pollution is much lower for organic farming than conventional farming. In the following section, we will present the calculated environmental efficiency for 2 types of farming and the main results of our empirical studies.

5 Results

5.1 The estimated environmental efficiency

The first part of the study concerns the econometric estimation of both technical and environmental efficiency with a translog production model. Before turning to the second stage of the study which has the attempts to figure out the effect of organic farming on environmental efficiency, we first check the relevance of the stochastic frontier model and the second on the significance of technical efficiency.

[see Table 5, p.22 around here]

First, the model must be relevant. Hence, we check the theoretical consistency of our estimated efficiency model by verifying that the marginal products are positive. In other words, if this theoretical criterion is empirically checked, then the obtained efficiency estimates can be considered as consistent with microeconomic theory. As the coefficients of the translog functional form do not allow any direct interpretation of the magnitude and significance of individual output elasticities, the latter were computed for all inputs at the sample mean and median (from the coefficients of column (1)[22].

In our case, the paddy rice production depends more strongly on Nitrogen input (0.37) and water (0.13) at sample mean. These findings suggest that efficiency gains are most likely with respect to Nitrogen input and water. However, at both sample mean and sample median, the marginal productivity of labor is negative. This result does not validate the theoretical predictions but it seems to be relevant within the context of Chinese agriculture. According to many other studies, surplus labor may exist in China's agriculture (Wan and Cheng, 2001; Fan et al., 2003). The over-use of labor input implies that the marginal productivity of labor then must be very low, even negative in some cases (Tian and Wan, 2000; Tan et al., 2010; Chen et al., 2006). Also, the returns to scale at sample mean and sample median are positive. Thereby, the production technology and inputs used are relevant to estimate technical efficiency.

Second, technical efficiency is significant, suggesting that the translog stochastic production frontier seems to be relevant to estimate technical efficiency and so for assess environmental efficiency.

5.2 Performance of organic farming in terms of environmental efficiency

5.2.1 Environmental efficiency of organic farming over time

Table 6 presents the result of the effect of organic farming on environmental efficiency before and after 2009, year when organic farming project has enlarged its scale in Sancha village. As demonstrated in Section 2, along with the process of scaling up, organic farmers (mainly the new converted) tended to use more external N input. Performance of organic farming in terms

---

[22] The coefficients estimated in the translog specification are not the input's elasticity and so the result cannot be easily interpreted as in the constant-elasticity Cobb–Douglas case. The elasticities of mean output with respect to the j^{th} input variable are calculated at the means of the log of the input variable and their second order coefficients as follows:

$$\frac{\delta lnY}{\delta X_j} = \beta_j + 2.\beta_{jj}\overline{lnX_j} + \Sigma_{j \neq k}^{K} \beta_{jk}\overline{lnX_k}. \tag{13}$$

of soil surface N balance has decreased significantly after 2009. Intuitively, one can expect that environmental efficiency of organic farming should decreased as well after 2009.

The regression of equation 11 is made by four estimators. The first one is the OLS estimator and provides a "naive" estimation by not taking into account (1) the presence of unobserved and time–invariant individual effects, and (2) the endogeneity of organic farming. To solve the first issue, the Within estimator is used from columns 5 to 8 whereas the 2SLS estimator deals with the second issue in columns 9–12. Finally, a Within-2SLS estimator allows for the consideration of the two issues from columns 13–16. Moreover, we present a step by step analysis by adding successively from the basic regression (column 1 for OLS estimator, column 5 for Within estimator, column 9 for 2SLS estimator and column 13 for Within–2SLS estimator) the dummy variable 2009 and the interaction term $organic * 2009$. Finally, we added the variable of external N input lnN in hope that the excessive use of N input could explain the eventually loss of environmental efficiency over time.

[see Table 6, p.23 around here]

To deal with the eventual endogenous problem of organic farming, we have 2 excluded instruments, the geographical distance from farmer's house to the plot and the presence of chemical fertilizer pollution around the plot. According to the field observation, organic farming demand much more labor mainly on the transport and application of organic compost and manure, the long distance from house will thus generate a big cost and discourage the organic farming. Meanwhile, the presence of chemical fertilizer pollution around the plot will make the organic farming non credible thus discourage this practice. From Table 5 of the first stage regressions, we note that these 2 instruments are both significant, while the Sargan test also supports their validity.

Organic farming is found to have a positive and significant effect after controlling for (1) the individual fixed effects (cols. 5 and 13) and (2) the dummy variable 2009. However, the interaction term has a negative and significant effect (except for the 2SLS estimator but the sign is negative) while the additive variable of organic farming has a positive and significant effect (except for the OLS and 2SLS estimator but the sign is positive). This result confirms our intuition about the loss of environmental efficiency after 2009. Whilst before 2008, organic farming was more efficient than conventional farming. After control of external N input, the effect of organic farming disappeared. Although the N input is probably endogenous and we may have biased estimates for its effect on the environmental efficiency, this first result indicates that the effect of organic farming is sensitive to the external N input. N input level may be a critical condition for organic farming to be more efficient than conventional farming. In order to justify this hypothesis, we proceed to the second step of estimation.

5.2.2 Environmental efficiency of organic farming on different external N input level

Since the N input is probably endogenous, we will precede it in an alternative way instead of putting it directly into the equation. We divided the total sample into 3 equal sub-samples according to the level of external N input, namely the high, the medium and the low sub–samples. The regression of equation 12 is done within each of these 3 sub-samples by the same four estimators (OLS, Within, 2SLS and Within-2SLS). Table 8 presents these results.

[see Table 8, p.26 around here]

One can note that the effects of organic farming on environmental efficiency are different within 3 sub-samples. On low N input level (low sub-sample), we found that organic farmers generally have a higher environmental efficiency than non organic farmers[23]. On medium level, the effect of organic farming is positive or non significant. However, on high input level, Organic farmers have a lower environmental efficiency, or at least, the difference between organic and conventional farming is not significant [24].

This observation is crucial to understand the condition and the extent to which organic farming could be environmental sound. Organic farming is not necessarily more environmentally efficient than conventional farming unless the nutrient input is low. This result seems to be more favorable for small holder organic farming in developing country where the nutrient input is generally on low level. Nevertheless, this condition should be revised when industrialization of organic farming emerged in developing countries recently. From the point view of environmental efficiency, small is more beautiful!

6 Discussion and conclusion

Within the context of sustainable development, organic farming has emerged as a hope of the future. From the point of view of environment protection, organic farming is supposed to minimize the external nutrient input for the agricultural production. While from an economic point of view, organic farming should meet the requirement of food security to feed the world. The indicator of environmental efficiency takes both aspects into consideration, and privilege the role of environment protection for organic farming. Under the framework of stochastic frontier analysis, we calculate the environmental efficiency for paddy rice production in a small village in China. Our empirical estimation reveals that organic farming is not necessarily more efficient than conventional farming over time. For high input production, conventional farming can produce more with less external Nitrogen input. This is the main explanation to the loss

---

[23] The sign is not significant for the Within and Within–2SLS estimators.

[24] In spite of the fact that the effect is negative for all estimators, the sign is not significant for the Within and Within–2SLS estimators.

of efficiency when organic farming project is scaling up and farmers tend to increase external nitrogen input.

Why this happened? There may be structural mechanism if significant difference lies between technologies of organic and conventional farming. According to observation of agronomist, output of organic farming is not sensitive to external Nitrogen input over certain critical level. On the contrary, excessive use of organic nutrient is harmful to the crops and eventually reduces the output. Generally, organic farming will find less nutrient loss because of rich organic matters in the soil, that's the reason why organic farming needs less external nitrogen input and it is easier to overuse it. This explanation will need more support from scientific experimentation of agronomy. But if this is the case, organic farmers on high level of Nitrogen input may probably overuse the N input and find their efficiency decreased.

On the other hand, there may institutional explanation. As mentioned earlier, for new converted to organic farming, the lack of experience and fear for loss from conversion will drive them to use more external nitrogen input, whilst these characters can also reduce their environmental efficiency. If this is the case, more institutional support (i.e. extension service) is required to reinforce farmers' capacity and confidence for organic farming. Alternatively, the social mechanism can also be explored to improve the performance of organic farming. After all, further and more profound study is needed to identify the real underlying mechanism.

As an elementary study, there are several limits in our study. First of all, if data available, we should take into consideration more aspects other than external nitrogen input (i.e. nitrogen loss to environment) to calculate the environmental efficiency. Broadly, organic farming has positive environmental impact compared to conventional farming in terms of soil organic matters and ecological diversity. While this improvement will certainly have impact on the productivity in a long run, it is not possible to be observed within 5 crops seasons. We will need data for longer period to be able to evaluate the potential environmental efficiency of organic farming.

References

Aigner, D., Lovell, C. A. K., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. Journal of Econometrics 6 (1), 21–37.

Avery, D. T., 1998. The hidden dangers of organic food. American Outlook, 19–22.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avilès-Vaquez, K., Samulon, A., Perfecto, I., 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 22 (02), 86–108.

Bank, T. W., 2005. Agricultural Growth For The Poor: An Agenda For Development. World Bank Publications.

Bank, W., 2009. World Development Report 2010: Development and Climate Change. World Bank Publications.

Battese, G. E., Coelli, T. J., 1992. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in india. Journal of Productivity Analysis 3 (1-2), 153–169.

Chen, Z., Huffman, W., Rozelle, S., 2006. Farm technology and technical efficiency: Evidence from four regions in china. Tech. Rep. 12605, Iowa State University, Department of Economics.

Christensen, L. R., Jorgenson, D. W., Lau, L. J., 1971. Conjugate duality and the transcendental logarithmic function. Econometrica 39 (4).

Connor, D. J., 2008. Organic agriculture cannot feed the world. Field Crops Research 106 (2), 187–190.

Cuesta, R. A., Lovell, C. K., Zofo, J. L., June 2009. Environmental efficiency measurement with translog distance functions: A parametric approach. Ecological Economics 68 (8-9), 2232–2242.

Damiani, O., 2002. The Adoption of Organic Agriculture Among Small Farmers in Latin America and the Caribbean: Thematic Evaluation. International Fund for Agricultural Development.

Day, A., 2008. The end of the peasant? new rural reconstruction in china. Boundary 2 35 (2), 49–73.

Diewert, W. E., 1971. An application of the shephard duality theorem: A generalized leontief production function. The Journal of Political Economy 79 (3), 481–507.

Fan, S., Zhang, X., Robinson, S., 2003. Structural change and economic growth in china. Review of Development Economics 7 (3), 360–377.

F.A.O, 2002. Organic Agriculture, Environment and Food Security. F.A.O.

Fuss, M., McFadden, D. L., 1978. , Production Economics: A Dual Approach to Theory and Applications Volume I: The Theory of Production. North-Holland Publishing Company.

Greene, C., 2009. Emerging issues in the US organic industry. No. 55. DIANE Publishing.

Hine, R., Pretty, J. N., Twarog, S., 2008. Organic agriculture and food security in Africa. United Nations.

Jia'en, P., Jie, D., 2011. Alternative responses to the modern dream: the sources and contradictions of rural reconstruction in china. Inter-Asia Cultural Studies 12 (3), 454–464.

Kilcher, L., 2007. How organic agriculture contributes to sustainable development. Journal of Agricultural Research in the Tropics and Subtropics, Supplement 89, 31–49.

Kirchmann, H., Esala, M., Morken, J., Ferm, M., Bussink, W., Gustavsson, J., Jakobsson, C., 1998. Ammonia emissions from agriculture. Nutrient Cycling in Agroecosystems 51 (1), 1–3.

Kumbhakar, S. C., Lovell, C. K., 2000. Stochastic Frontier Analysis. Cambridge: Cambridge University Press.

Leibenstein, H., 1966. Allocative efficiency vs. x-efficiency. American Economic Review 56 (3), 392–415.

Meeusen, W., van den Broeck, J., 1977. Efficiency estimation from cobb-douglas production functions with composed error. International Economic Review 18 (2), 435–444.

OECD, 2001. Environmental Indicators for Agriculture: Methods and Results. OECD Publishing.

Pretty, J. N., 1995. Regenerating agriculture: policies and practice for sustainability and self-reliance. Natl Academy Pr.

Pretty, J. N., Hine, R., 2001. Reducing food poverty with sustainable agriculture: A summary of new evidence. University of Essex UK.

Reinhard, S., Lovell, C. A. K., Thijssen, G., 1999. Econometric estimation of technical and environmental efficiency: An application to dutch dairy farms. American Journal of Agricultural Economics 81 (1), 44–60.

Reinhard, S., Thijssen, G., 2000. Nitrogen efficiency of dutch dairy farms: a shadow cost system approach. European Review of Agricultural Economics 27 (2), 167–186.

Tan, S., Heerink, N., Kuyvenhoven, A., Qu, F., 2010. Impact of land fragmentation on rice producers technical efficiency in South-East china. NJAS - Wageningen Journal of Life Sciences 57 (2), 117–123.

Tian, W., Wan, G. H., 2000. Technical efficiency and its determinants in china's grain production. Journal of Productivity Analysis 13 (2), 159–174.

Twarog, S., 2006. Organic agriculture: A trade and sustainable development opportunity for developing countries. Trade and Environment Review, 141–223.

Wan, G. H., Cheng, E., 2001. Effects of land fragmentation and returns to scale in the chinese farming sector. Applied Economics 33 (2), 183–194.

Willer, H., Rohwedder, M., Wynen, E., 2009. Organic agriculture worldwide: current statistics. The world of organic agriculture. Statistics and emerging trends, 25–58.

Zhu, Z. L., Chen, D. L., 2002. Nitrogen fertilizer use in china: Contributions to food production, impacts on the environment and best management strategies. Nutrient Cycling in Agroecosystems 63 (2), 117–127.

7 Appendix

7.1 Definition of variable and descriptive statistics

Table 3: Definition of variables

Variable Name	Definition and description
Organic	Farmer's self report organic status. It's a binary variable code "1" if the plot is under organic management. Code "0" otherwise.
Yield	The quantity of raw rice harvested from the plot at end of the season, the unit is "yuan/mu".
Labor	Hours spent in paddy rice production on the plot. It is weighted by the age of farmer. The unit is "yuan/mu".
N	The external Nitrogen input from organic source or inorganic source for the paddy rice production on the plot. The unit is "yuan/mu".
Capital	Money spent for the rice production on the plot including the machinery, employment and seed cost. The unit is "yuan/mu".
Water	Index of water availability to the plot, range from 0 to 2. High index means good water availability.
Area	Area of the plot dedicated to paddy rice production, the unit is "Mu".
Age	The age of the household head.
Sex	The Sex of the household head.
Education	Year of education of the household head.
Geography	The situation of plot with "1" in the mountains and "0" in cultivated zone.
Quality	The score of plot's quality in terms of fertility evaluated by farmer. Range from 1 to 3, high score means high fertility.
Distance	The geographical distance from farmer's house to the plot. Evaluated by farmer in terms of minutes of walk. Range from 1 to 4.
Pollution	The presence of pollution from chemical fertilizer application near the plot: "1" for yes and "0" for no.
Seed	Seven different species of rice seeds used during the 5 seasons coded from 0 to 6.

Table 4: Descriptive Statistics

Variables	Mean	Standard deviation	Median	Min	Max
Log of rice output	6.487	(0.297)	4.472	7.313	1,012
Log of labor	4.781	(0.418)	3.348	5.825	1,012
Log of capital	4.044	(0.741)	1.322	5.58	1,012
Log of water	0.877	(0.326)	0	1.099	1,012
Log of N	3.302	(0.285)	2.298	4.234	1,012
Organic farming (=1)	0.341	(0.474)	0	1	1,012
Age in years of the household head	54.587	(12.588)	28	79	1,012
Sex of the household head (=1 if woman)	0.607	(0.489)	0	1	1,012
Education of the household head	3.639	(3.298)	0	12	1,012
Area in mu of the plot	0.382	(0.204)	0.1	1.3	1,012
Geographical situation (=1 if in mountains)	0.069	(0.254)	0	1	1,012
Soil quality of the plot (from 1 to 3)	2.333	(0.767)	1	3	1,012
Seed used on the plot (from 0 to 6)	1.922	(2.526)	0	6	1,012
Technical efficiency	0.724	(0.122)	0.345	0.976	1,012
Environmental efficiency	0.45	(0.184)	0.082	0.962	1,012

Authors' calculation.

7.2 Results

Table 5: Stochastic production frontier model

Dependent variable: rice output				
			Input elasticities	
	(1)	(2)	(3)	(4)
Variables	Coefficient estimate	Standard error	Sample mean	Sample median
Labor	0.884*	0.481	-0,045	-0.059
Capital	1.361***	0.191	0.079	0.126
Water	0.835**	0.395	0.127	0.153
N	0.105	0.453	0.372	0.331
Labor squared	-0.097**	0.046		
Capital squared	-0.165***	0.017		
Water squared	0.075	0.059		
N squared	-0.025	0.068		
Labor*Capital	-0.033	0.036		
Labor*Water	-0.083	0.063		
Labor*N	0.062	0.068		
Capital*Water	0.006	0.031		
Capital*N	0.0623*	0.036		
Water*N	-0.141*	0.074		
Seed	-0.015***	0.003		
Intercept	0.884	1.496		
Observations	1,012			
♯ households	203			
χ^2 statistic	691.451			
Log-likelihood	241.114			
Sig-u (TE.)	0.205			
Sig-v (errors.)	0.155			
$H_0 : \mu = 0$	0.286***			
$H_0 : \eta = 0$	0.033*			
$H_0 : \gamma = 0$	0.569*			

Estimation method: Maximum likelihood estimator with time-variant technical efficiency. $H_0 : \mu = 0$, $H_0 : \eta = 0$ and $H_0 : \gamma = 0$ report alternatively the null hypotheses that the technical inefficiency effects (1) have a half-normal distribution, (2) are time invariant and (3) present in the model. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 6: Differential time effect of organic farming on environmental efficiency

Dependent variable: environmental efficiency																
	OLS estimator				Within estimator				2SLS estimator				2SLS-Within estimator			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Organic	-.008	-.009	0.021	0.011	0.016***	0.012***	0.017***	0.0007	-.002	-.008	0.015	0.006	0.014*	0.009	0.02**	0.008
	(0.014)	(0.014)	(0.024)	(0.024)	(0.004)	(0.004)	(0.005)	(0.005)	(0.025)	(0.026)	(0.045)	(0.045)	(0.008)	(0.008)	(0.009)	(0.009)
2009		0.024**	0.041***	0.04***		0.017***	0.019***	0.017***		0.026**	0.034**	0.033**		0.018***	0.021***	0.018***
		(0.012)	(0.014)	(0.014)		(0.003)	(0.003)	(0.003)		(0.012)	(0.016)	(0.016)		(0.003)	(0.004)	(0.004)
2009*Organic			-.049*	-.035			-.007*	0.004			-.030	-.017			-.012**	-.002
			(0.027)	(0.027)			(0.004)	(0.004)			(0.046)	(0.046)			(0.005)	(0.006)
Area	-.201***	-.216***	-.198***	-.211***					-.202***	-.202***	-.200***	-.214***				
	(0.029)	(0.029)	(0.029)	(0.028)					(0.029)	(0.029)	(0.029)	(0.029)				
Age	-.002***		-.002***	-.002***	0.014***	0.004*	0.004*	0.007***	-.002***	-.002***	-.002***	-.002***	0.015***	0.004*	0.004*	0.007***
	(0.0005)		(0.0005)	(0.0005)	(0.001)	(0.002)	(0.002)	(0.002)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.001)	(0.002)	(0.002)	(0.002)
Sex	-.006	0.007	-.004	-5.46e-06					-.006	-.005	-.005	-.001				
	(0.012)	(0.012)	(0.012)	(0.012)					(0.012)	(0.012)	(0.012)	(0.012)				
Education	-.004**	-.001	-.004**	-.003*					-.004**	-.004**	-.004**	-.003*				
	(0.002)	(0.002)	(0.002)	(0.002)					(0.002)	(0.002)	(0.002)	(0.002)				
Geography	-.044**	-.041**	-.047**	-.047**					-.043**	-.044**	-.045**	-.045**				
	(0.02)	(0.02)	(0.02)	(0.02)					(0.02)	(0.02)	(0.02)	(0.02)				
Soil quality	0.025***	0.028***	0.027***	0.028***					0.024***	0.025***	0.025***	0.026***				
	(0.008)	(0.008)	(0.008)	(0.008)					(0.009)	(0.009)	(0.009)	(0.009)				
Seed	0.006**	0.004	0.004*	0.005**	0.001**	0.002***	0.002***	0.003***	0.005*	0.004	0.004	0.005	0.002***	0.002***	0.002***	0.002***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.003)	(0.003)	(0.003)	(0.003)	(0.0006)	(0.0006)	(0.0006)	(0.0005)
N				-.071***				-.052***				-.073***				-.049***
				(0.019)				(0.008)				(0.02)				(0.008)
Intercept	0.6***	0.449***	0.579***	0.806***	-.347***	0.197	0.192	0.236*	0.601***	0.589***	0.584***	0.817***				
	(0.037)	(0.025)	(0.037)	(0.067)	(0.069)	(0.121)	(0.122)	(0.121)	(0.037)	(0.037)	(0.038)	(0.071)				
Observations	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012
♯ households	203	203	203	203	203	203	203	203	203	203	203	203	203	203	203	203
F statistic	17.257	14.576	14.924	16.881	82.889	82.547	69.65	66.594	17.328	16.194	14.599	16.876	87.492	77.225	61.979	70.128
Adjusted R2	0.098	0.083	0.104	0.115	0.269	0.291	0.293	0.369	0.098	0.102	0.104	0.114	0.085	0.111	0.113	0.207
RMSE	0.174	0.176	0.174	0.173	0.023	0.023	0.023	0.022	0.174	0.173	0.173	0.172	0.026	0.025	0.025	0.024
Hansen statistic									1.41	1.708	2.089	1.777	0	0	0.488	0.629
Hansen p-value									0.235	0.191	0.352	0.411	.	.	0.485	0.428

Note: OLS robust standard errors in parentheses. Columns 1–4 report results with the OLS estimator, Columns 5–8 report results with the Within estimator, Columns 9–12 report results with the 2SLS estimator and Columns 13–16 report results with the 2SLS-Within estimator. Area, sex, education, geography and soil quality are invariant variables. In columns 13–14, the Hansen statistics is zero since there is only one IV (distance is time invariant). *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 7: First stage regressions

Depend Variable Col. Table 6	Organic col.9	Organic col.10	Organic col.11	2009*Organic col.11	Organic col.12	2009*Organic col.12	Organic col.13	Organic col.14	Organic col.15	2009*Organic col.15	Organic col.16	2009*Organic col.16
Excluded instruments												
Distance	-.046***	-.046***	-.024	0.02*	-.023	0.02*						
	(0.014)	(0.014)	(0.016)	(0.011)	(0.016)	(0.011)						
Chemicals influence	-.555***	-.555***	-.622***	0.436***	-.615***	0.431***	-.586***	-.586***	-.629***	0.489***	-.583***	0.479***
	(0.031)	(0.031)	(0.055)	(0.05)	(0.055)	(0.05)	(0.066)	(0.066)	(0.077)	(0.097)	(0.076)	(0.093)
2009*distance			0.029*	-.055***	0.03**	-.055***			-.012	-.050**	-.013	-.046*
			(0.015)	(0.013)	(0.015)	(0.013)			(0.019)	(0.025)	(0.018)	(0.024)
2009*chemicals influence			0.614***	-.656***	0.605***	-.647***			0.4***	-.667***	0.363***	-.638***
			(0.056)	(0.038)	(0.056)	(0.038)			(0.085)	(0.069)	(0.081)	(0.069)
Included instruments												
Organic				0.652***		0.654***				0.702***		0.747***
				(0.034)		(0.033)				(0.06)		(0.057)
2009	0.063***	0.063***	-.785***	0.91***	-.778***	0.9***	0.111***	0.111***		0.901***		0.867***
	(0.022)	(0.022)	(0.052)	(0.035)	(0.052)	(0.035)	(0.032)	(0.032)		(0.069)		(0.068)
2009*organic			0.938***		0.941***				0.569***		0.572***	
			(0.012)		(0.013)				(0.068)		(0.062)	
Area	0.054	0.054	-.027	0.051**	-.042	0.063**						
	(0.046)	(0.046)	(0.032)	(0.025)	(0.032)	(0.026)						
Age	-.003***	-.003***	-.0007	-.0003	-.0006	-.0003	-.023	-.023	-.011	-.001	0.003	-.011
	(0.0009)	(0.0009)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.018)	(0.018)	(0.008)	(0.007)	(0.009)	(0.008)
Sex	0.103***	0.103***	0.032**	0.009	0.036***	0.005						
	(0.024)	(0.024)	(0.014)	(0.012)	(0.014)	(0.011)						
Education	0.007*	0.007*	0.002	0.0009	0.003	0.00004						
	(0.004)	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)						
Geography	-.018	-.018	0.005	-.013	0.004	-.012						
	(0.04)	(0.04)	(0.025)	(0.02)	(0.024)	(0.02)						
Soil quality	0.061***	0.061***	0.023**	0.0007	0.024**	-.0003						
	(0.015)	(0.015)	(0.01)	(0.008)	(0.01)	(0.008)						
Seed	0.048***	0.048***	0.02***	-.001	0.021***	-.002	0.025***	0.025***	0.012***	0.005	0.013***	0.002
	(0.006)	(0.006)	(0.004)	(0.003)	(0.004)	(0.003)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)	(0.003)
N					-.081***	0.068***					-.280***	0.221***
					(0.027)	(0.021)					(0.063)	(0.049)
Intercept	0.597***	0.597***	0.728***	-.559***	0.979***	-.768***	1.916**	1.916**	1.301***	-.494	1.434***	-.677
	(0.088)	(0.088)	(0.073)	(0.062)	(0.107)	(0.087)	(0.955)	(0.955)	(0.453)	(0.415)	(0.446)	(0.438)
Observations	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012	1,012
♯ households	203	203	203	203	203	203	203	203	203	203	203	203
F–stat	281.835	281.835	4,428.508	1,737.079	3,606.627	1,631.286	44.698	44.698	.	339.573	.	264.475
Adjusted R2	0.539	0.539	0.821	0.852	0.823	0.854	0.436	0.436	0.668	0.786	0.7	0.796
RMSE	0.322	0.322	0.2	0.167	0.199	0.166	0.178	0.178	0.136	0.151	0.13	0.148
Excluded IV F-stat	192.57	184.23	98.69	177.26	98.24	169.48	170.26	164.84	87.05	233.47	89.83	218.05

Note: OLS robust standard errors in parentheses. Columns 1–6 report results with the OLS estimator, Columns 7–12 report results with the Within estimator. Area, sex, education, geography and soil quality are invariant variables. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 8: Organic farming, N input and environmental efficiency

Dependent variable: environmental efficiency																
	OLS estimator				Within estimator				2SLS estimator				2SLS-Within estimator			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Organic	-.014	-.101***	0.019	0.042*	0.005	-.010	0.027***	0.005	-.008	-.096**	-.014	0.089*	0.004	-.015	0.035**	0.015
	(0.014)	(0.023)	(0.026)	(0.025)	(0.004)	(0.012)	(0.007)	(0.008)	(0.026)	(0.04)	(0.041)	(0.051)	(0.007)	(0.018)	(0.016)	(0.013)
Area	-.214***	-.409***	-.218***	-.108***					-.214***	-.409***	-.214***	-.119***				
	(0.029)	(0.058)	(0.051)	(0.041)					(0.029)	(0.057)	(0.051)	(0.042)				
Age	-.002***	-.003***	-.002***	-.002**	0.017***	0.019***	0.017***	0.012***	-.002***	-.003***	-.002***	-.002**	0.017***	0.019***	0.016***	0.012***
	(0.0005)	(0.0008)	(0.0007)	(0.0008)	(0.001)	(0.002)	(0.002)	(0.004)	(0.0005)	(0.0008)	(0.0007)	(0.0008)	(0.001)	(0.002)	(0.002)	(0.004)
Sex	-.0005	-.044**	0.003	0.004					-.001	-.044**	0.008	0.001				
	(0.012)	(0.022)	(0.022)	(0.019)					(0.012)	(0.021)	(0.021)	(0.019)				
Education	-.003*	-.005	-.006*	-.006*					-.003*	-.005	-.006*	-.007**				
	(0.002)	(0.003)	(0.003)	(0.003)					(0.002)	(0.003)	(0.003)	(0.003)				
Geography	-.046**	0.005	-.047	-.053*					-.044**	0.006	-.054	-.046				
	(0.019)	(0.034)	(0.039)	(0.032)					(0.02)	(0.034)	(0.038)	(0.033)				
Soil quality	0.027***	0.067***	0.009	0.011					0.026***	0.067***	0.014	0.003				
	(0.008)	(0.016)	(0.015)	(0.012)					(0.009)	(0.016)	(0.016)	(0.014)				
Seed	0.006**	0.017***	0.002	-.004	0.004***	0.004***	0.003***	0.004***	0.005	0.017***	0.005	-.008	0.004***	0.004***	0.003***	0.004***
	(0.003)	(0.005)	(0.005)	(0.005)	(0.0006)	(0.001)	(0.001)	(0.001)	(0.003)	(0.005)	(0.005)	(0.006)	(0.0006)	(0.001)	(0.0009)	(0.001)
N	-.071***	-.160**	-.206	0.015	-.033***	-.057*	0.032	-.004	-.071***	-.161**	-.221	0.013	-.033***	-.059**	0.043	-.002
	(0.02)	(0.078)	(0.146)	(0.048)	(0.007)	(0.033)	(0.033)	(0.017)	(0.02)	(0.075)	(0.144)	(0.046)	(0.007)	(0.028)	(0.032)	(0.016)
Intercept	0.808***	1.193***	1.297***	0.51***	-.396***	-.409**	-.616***	-.210	0.81***	1.197***	1.333***	0.53***				
	(0.07)	(0.297)	(0.486)	(0.151)	(0.071)	(0.165)	(0.145)	(0.222)	(0.069)	(0.285)	(0.477)	(0.152)				
Observations	1012	338	340	334	1012	338	340	334	1012	338	340	334	1012	314	304	305
♯ households	203	117	146	130	203	117	146	130	203	93	110	101	203	93	110	101
Adjusted R2	0.112	0.246	0.081	0.064	0.416	0.417	0.47	0.36	0.112	0.246	0.076	0.05	0.268	0.161	0.153	0.023
F–stat	14.302	11.758	3.947	3.551	71.963	22.825	32.753	22.316	14.37	11.208	4.469	3.427	80.159	25.832	25.871	19.248
RMSE	0.173	0.175	0.179	0.154	0.021	0.018	0.014	0.018	0.172	0.171	0.176	0.152	0.023	0.022	0.019	0.023
Hansen statistics									1.546	4.53	0.005	0.184	0	0	0	0
Hansen p-value									0.214	0.033	0.943	0.668				

Note: OLS robust standard errors in parentheses. In all regressions, seasons dummies are introduced (omitted season is season 1). Columns 1–4 report results with the OLS estimator, Columns 5–8 report results with the Within estimator, Columns 9–12 report results with the 2SLS estimator and Columns 13–16 report results with the 2SLS-Within estimator. Area, sex, education, geography and soil quality are invariant variables. In columns 13–16, the Hansen statistics is zero since there is only one IV (distance is time invariant). *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 9: First stage regressions of Table 8

Depend Variable	Organic	Organic	Organic	Organic	Organic	Organic	Organic	Organic
Col. Table **??**	col.9	col.10	col.11	col.12	col.13	col.14	col.15	col.16
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Excluded IV								
Distance	-.045***	-.040	-.027	-.062**				
	(0.014)	(0.025)	(0.023)	(0.026)				
Chemicals influence	-.551***	-.567***	-.608***	-.499***	-.574***	-.551***	-.383***	-.644***
	(0.031)	(0.051)	(0.05)	(0.063)	(0.066)	(0.143)	(0.137)	(0.113)
Included IV								
Area	0.056	0.053	0.057	0.081				
	(0.047)	(0.101)	(0.073)	(0.082)				
Age	-.002***	0.0005	-.003*	-.004**	0.044***	-.010	0.042**	0.024
	(0.0009)	(0.002)	(0.001)	(0.002)	(0.011)	(0.011)	(0.017)	(0.015)
Sex	0.103***	0.106**	0.101***	0.11***				
	(0.024)	(0.044)	(0.036)	(0.042)				
Education	0.008*	0.012*	-.001	0.017**				
	(0.004)	(0.007)	(0.006)	(0.008)				
Geography	-.018	-.063	-.080	0.028				
	(0.04)	(0.055)	(0.059)	(0.087)				
Soil quality	0.06***	0.009	0.076***	0.078***				
	(0.015)	(0.029)	(0.027)	(0.025)				
Seed	0.053***	0.057***	0.049***	0.05***	0.024***	0.008	0.018**	0.009
	(0.006)	(0.01)	(0.009)	(0.012)	(0.005)	(0.006)	(0.008)	(0.008)
N	-.025	0.114	-.397	-.096	-.293***	-.321*	-1.125***	-.263**
	(0.044)	(0.17)	(0.246)	(0.135)	(0.099)	(0.182)	(0.343)	(0.129)
Intercept	0.641***	0.06	1.862**	0.926**	-.704	2.423**	2.002**	0.302
	(0.172)	(0.648)	(0.815)	(0.467)	(0.59)	(1.090)	(1.004)	(0.771)
Observations	1012	338	340	334	1012	338	340	334
♯ households	203	117	146	130	203	117	146	130
F–stat	208.615	82.925	109.163	62.016	33.723	3.855	4.535	11.161
Adjusted R2	0.542	0.563	0.613	0.457	0.466	0.418	0.391	0.499
RMSE	0.321	0.319	0.298	0.339	0.173	0.108	0.112	0.121
Excluded IV F-stat	178.91	67.98	77.95	40.05	162.68	22.64	9.74	38.15

Note: OLS robust standard errors in parentheses. Columns 1–6 report results with the OLS estimator, Columns 7–12 report results with the Within estimator. Area, sex, education, geography and soil quality are invariant variables. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.