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The environmental efficiency of organic farming in developing countries: a case study from China

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Résumé / Abstract

In this case study, we attempt to re–evaluate the performance of organic farming in developing countries using the indicator of Environmental Efficiency (EE) within the framework of Stochastic Frontier Analysis (SFA). A set of plot–season level panel data was collected from an NGO–led organic paddy rice project in southern China. This original dataset is used to calculate EE scores across both the organic and conventional plots. Our two–stage analysis reveals two essential points. First, in poor rural areas, organic farming doesn't systematically reduce the pure nitrogen input for paddy rice production. In order to maintain the yield, organic farmers may apply the same, or an even greater quantity of pure nitrogen than conventional farmers. Second, organic farming loses its environmental efficiency in the scaling up period due to the excessive pure nitrogen input. Therefore, we argue that beyond the simple substitution of chemical fertilizer by organic fertilizer, more sustainable organic farming necessitates additional efforts on the control of nutrient input.

Mots clés / Key words : Organic farming, Environmental efficiency, Stochastic frontier analysis, China.

Codes JEL / JEL codes : Q12, Q57, R15, O53, D71

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1 Introduction

Nowadays, sustainable agriculture catches more and more attention in the context of modern agriculture's excessive dependence on high-energy use and deterioration of agro–ecosystem. Here, the definition of sustainability refers to agriculture's capacity to maintain its productivity while preserving the natural environment over the long run. However, the complex interrelationships between agricultural production and the natural environment make it extremely difficult to determine which methods and systems in different locations will actually lead to sustainability (Ikerd, 1993).

Regarded as a paradigm of sustainable agriculture, organic farming demonstrates significant environmental benefits in terms of agricultural pollution reduction, soil health recovery and biodiversity improvement etc. It has thus been promoted on a global scale during recent decades (Willer et al., 2009; FAO, 2002; IFAD, 2002; WorldBank, 2009; Twarog, 2006; Kilcher, 2007; Hine et al., 2008). However, the sustainability of organic farming system has also long been questioned in developed, as well as in developing, countries. For example, in Europe, agricultural productivity could decrease by 20-50 percent by conversion to organic farming on a large scale (Avery, 1998; Connor, 2008; Mayen et al., 2010). While smallholder organic farming in developing countries seems to suffer less from productivity reduction (Pretty and Hine, 2001; Badgley et al., 2007), the major concern continues to be the insufficient supply of organic fertilizer in poor rural areas. Moreover, an often neglected problem involves the pollution of organic nutrients. Indeed, excessive use of external nutrients from both organic and inorganic sources will generate negative environmental effects, e.g., the leaching of nitrates from organic manure and the accumulation of heavy metals in soil following the application of Bordeaux mixture. Moreover, ammonia volatilization is mainly caused by animal manure rather than by chemical nitrogen fertilizers (Pretty, 1995; Kirchmann et al., 1998). Hence, the real question regarding sustainability for organic farming in developing countries is whether organic farming systems use the minimum of external nutrients while maintaining the local mean yield.

To answer this question, an investigation of efficient use of external nutrients for organic farming is necessary. In the literature, Reinhard et al. (1999) has provided an indicator of Environmental Efficiency (EE) which aims to evaluate the efficient use of environment detrimental input. A methodological framework has been developed to calculate EE using a Stochastic Frontier Analysis (SFA) approach. For applications, this approach has provided useful insights into the environmental performance of Dutch dairy farming (Reinhard et al., 1999; Reinhard and Thijssen, 2000) as well as in other domains recently (Zhang et al., 2008). Inspired by these works, our case study attempts to apply this approach to the smallholder paddy rice production in the Chinese village of Sancha, within a NGO–led organic farming project. Specifically, we focus on the efficient use of pure nitrogen (hereafter called N) which is the most important nutrient input for paddy rice production. In addition, it is also the biggest pollutant to underground water and air resulting from agricultural production in China (Zhu and Chen, 2002; Ju et al., 2007). Using original survey data combined with agronomic data, we are able to calculate EE scores for both organic and conventional farming in the first step. In the second step, we compare the calculated EE between organic and conventional farming. The panel data (2008-2010) also allows us to investigate the variation of EE over time to check the robustness of our results.

Contrary to common wisdom, our study demonstrates that for smallholder rice production in China, organic farming does not systematically reduce the use of N. While chemical fertilizer is successfully substituted by organic fertilizer to maintain the yield, the quantity of N input remains the same, and sometimes even higher than conventional farming. *A priori*, organic farming is more environmentally efficient, but it loses its advantage when the level of N input increased. This result is also confirmed by the decreasing performance of organic farming during the scale-up period (after 2009). Therefore, more efficient organic farming necessitates additional efforts on the control of N input, especially during the scale-up period. To this end, effective technical support is more appropriate than subsidies to organic fertilizer. In conclusion, our study indicates the potential risk of sustainability for organic farming and sheds light on the conditions that organic farming could be more environmentally efficient. These conditions are crucial when governments and development agencies seek to promote sustainable agriculture in developing countries.

The remainder of this paper is organized as follows. Section 2 presents the organic farming project in the village and the evolution of paddy rice production. Section 3 describes the methodological framework and empirical method. Section 4 gives details of the data. Section 5 discusses the main results and Section 6 concludes.

2 An example of organic farming in a small Chinese village

Initiated by exports, organic farming has now become a rural development strategy in China. Since 2003, vibrant organic communities have been observed in rural China in conjunction with the social movement of New Rural Reconstruction that was initiated by scholars, students and social activists. In addition to the single "company+farmer" model, diverse models such as farmer's co–ops, farmer–participatory development and Community Supported Agriculture (CSA) have recently emerged to promote organic farming in China (Day, 2008; Pan and Du, 2011). In this study, we will focus on one of these innovative models in southern China.

The study area is located in Sancha village (109.01E/22.73N), a small and poor village in Guangxi province (see map 6 in Appendix)[1]. Due to the abundant water resources and tropical climate, paddy rice is one of the most important crops in this region. Since the 1980s', machinery and modern chemical inputs have been democratized in southern China. However, given its remote situation and poverty, Sancha village maintains its old tradition of paddy rice production, e.g., two crop seasons of rain fed culture, cattle tillage, use of cow dung fertilizer, etc. The average chemical fertilizer application level is about 16.76 kg/mu in the village[2] which is much lower than the average provincial level of 26.24 kg/mu[3]. Hence, both the less developed agriculture and the well preserved natural environment favor the organic farming development in this village.

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[1] Guangxi Zhuang autonomous region is a minority "Zhuang" dominated region where the economic development is low at the national level. Sancha village is a typical Zhuang dominated village with about 650 inhabitants.

[2] Calculated from the data of our household survey.

[3] Here, data comes from 2010 Guangxi Statistical Year Book.

In 2005, an organic farming project was introduced to the village by the local Maize Research Institution in partnership with an NGO, called Partnerships for Community Development (PCD), with the aim of promoting organic paddy rice production[4]. This project began with participatory experimentation among a small group of farmers. The NGO provided technical guidance and market support (CSA) to encourage conversion, while farmers had to decide the quantity of inputs according to their own observation and take responsibility for their yield. By means of these farmer participatory experimentations, organic farmers have found suitable nutrient formula to substitute the chemical fertilizer by self–produced compost and traditional organic inputs[5]. With respect to pest control, organic farmers have adopted the integrated rice–duck culture system[6] and the use of traditional medicinal plants, which appear to be efficient in preventing certain pests. In terms of the farmers' organization, a farmers' association was founded with support of the NGO in coordinating the project and monitoring farmers' organic production. More importantly, the routine regulation by the farmers' association guaranteed the respect of organic standards and the quality of organic produce which served as the basis of CSA. Without resorting to the official organic certification which is too costly for poor farmers, the farmers' association achieved consumer confidence with their self-regulation and the quality of their produce.

After 3 years of experimentation, the project entered into a novel phase of scaling up. Thanks to the rural community construction policy, more farmers got access to information about the organic farming project[7]. An acceleration of conversion to organic farming was observed in 2009. At the end of 2009, 73 percent of farmers in the village had conducted experiments on their paddy land. According to the field observation, we note that although organic farming was universally accepted mainly due to its high price

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[4] PCD is based in Hong Kong. More information about this NGO can be found from their site: `http://www.pcd.org.hk/eng/index.html`.

[5] Compost is produced by farmers using fish powder, bone powder, tea bran, peanut bran and bio gas slurry.

[6] The integrated rice–duck system consists of organic rice culture and raising ducks in the paddy simultaneously.

[7] The rural community construction is a policy promoted by the Ministry of Civil Affairs in China since 2007, it consists of rebuilding the rural community by means of infrastructures construction and social interaction

premium, farmers, especially newly converted farmers, still had doubts on its potential yield, [8]. Also, given the constraint of the labor force and organic nutrients, only 29 percent of the total paddies were converted to organic farming in 2009[9].

Sancha village is suitable for the comparative study from which we can draw a detailed picture of organic farming in poor rural areas. In this study, we refer to organic farming as a farmers' agricultural practice regulated by the organic rice project, which involved integral farm management such as a rice–duck system which excluded the use of chemical fertilizers and pesticides. This practice corresponded to the definition of organic farming by IFOAM though it was not certified by any official agency. For conventional farming, we refer to the local traditional practice which did not exclude the use of chemical inputs.

To understand the differences between these 2 systems, we collected inputs and output data by means of a household survey. Combined with the agronomic experimentation data of nitrogen content for each inputs provided by the local agronomist[10], we are able to calculate the pure nitrogen input as well as soil surface nitrogen balance[11] for both systems. Table 1 presents a summary. We can also observe the trend during five consecutive crop seasons (from 2008 to 2010)[12].

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[8] Through the CSA network, the price of organic rice is about two times that of conventional rice sold at local market.

[9] Data is derived from our fieldwork survey.

[10] Quantified inputs include chemical fertilizers, e.g., compound fertilizer (150gN/kg), Urea Fertilizer (460gN/kg); organic fertilizer, e.g., compost (15gN/kg); organic inputs, e.g., cow dung manure (3gN/kg), hen manure (10gN/kg), pig manure (6gN/kg) and straw (5kgN/mu). The output is raw rice (23gN/kg) and straw (5kgN/mu).

[11] The soil surface N balance is calculated following the method of OECD (2001) as the difference between the total quantity of pure N entering, and the quantity of pure N leaving, the soil surface over one production cycle. Since the aim of this approach is to investigate the global environmental impact of rice production, we didn't distinguish between the loss of N to ground water and air separately.

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

Table 1: Organic and 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)	**	0.0(3.7)	1.7(3.4)	**
season 2	313.7(92.6)	323.7(92.8)	ns	12.1(3.3)	12.9(3.8)	ns	-0.1(3.7)	0.5(3.3)	ns
season 3	339.0(91.8)	363.0(97.5)	*	15.4(4.5)	14.9(3.8)	ns	2.6(4.8)	1.6(3.2)	*
season 4	301.9(86.8)	316.5(102.8)	ns	14.4(3.9)	12.5(3.7)	***	2.5(4.1)	0.2(3.1)	***
season 5	363.5(72.8)	362.5(90.3)	ns	15.2(3.8)	14.6(3.6)	ns	1.8(4.1)	1.3(3.1)	ns

Notes: Data from author's household survey and agronomic experimentation data provided by local agronomist of the NGO. 1mu=1/15ha. The mean value is presented with standard deviation in parentheses. *** statistical significance at 0.1%, ** statistical significance at 1%, * statistical significance at 5%. "ns" means non–significant.

From Table 1, we note that organic farming has successfully coped with conventional farming in terms of yield. There has been no significant difference between organic farming and conventional farming in 5 crop seasons. This is in line with observations from other developing countries (Zhu et al., 2000; Pretty et al., 2003). However, in terms of the pure N input, organic farming hasn't done better than its counterparts in Sancha village. Especially during the scale-up period (since Season 3 in 2009), farmers tended to increase the use of N in Sancha village. In fact, this phenomenon is not isolated in the literature. For instance, Kirchmann and Ryan (2004) report Swedish studies in which mean N use in organic systems is close to that of conventional systems in Sweden. This phenomenon could be explained by the smallholder production on tiny plots which is totally possible to substitute the chemical N by organic N. Meanwhile, it is also due to the behavior of newly converted farmers to organic farming, according to the head of the farmers' association: "Since they (newly converted farmers) have less experience and confidence, they would generally apply more compost or animal manure for fear of yield loss from conversion."

Regarding the environmental impact, we could take a look at the soil surface N balance. A persistent deficit in nutrient budgets might indicate mining of soil nutrients, whilst a persistent surplus might indicate potential environmental pollution (OECD, 2001). We note that, at the mean level, both organic and conventional farming have displayed a varying

N surplus, ranging from -0.1kg/mu to 2.6kg/mu. Compared to other Chinese provinces, the N surplus level in Sancha village is quite low (Sun and Bouwman, 2008; Wang et al., 2007). While comparing to its neighbor countries such as Thailand, Bangladesh, Vietnam, it appears to be at a similar or higher level (Wijnhoud et al., 2003; Hossain et al., 2012; Mussgnug et al., 2006). Once again, the N balance indicates a significant loss of environmental performance for organic farming during the scale-up period, which highlights the necessity of N input optimization.

To summarize, in 5 consecutive crops seasons, organic farmers in Sancha village have achieved a satisfactory yield by substituting the chemical fertilizers with self–produced organic fertilizers. This is a big success from an agronomic point of view. However the environmental cost is still high as indicated by high N input and N accumulation in the soil, especially in the scale-up period(since 2009). Therefore, in order to re–evaluate the environmental performance of organic farming, we will need another indicator on basis of N-use efficiency which takes into account both yield and environmental cost. For this purpose, we now turn to the indicator of EE using SFA.

3 Calculation of EE and econometric estimation

The term of EE used in this study is defined by the minimum use of pure N input for a given level of output. This EE is different from the conventional Technical Efficiency (TE) and stresses the efficient use of pure N input, and thus efficiency of environment preservation. EE is calculated from TE with the classic approach of SFA. We apply a two–steps approach here as proposed by Reinhard et al. (1999). EE is firstly calculated from TE using SFA. Then, EE is regressed on organic farming.

3.1 Calculating EE with a SFA model

To determine the effect of organic farming on EE, we need first to calculate this efficiency. The way to achieve this is to introduce environmental variables into a traditional production function in order to derive EE from adjustments of conventional measures of TE.

TE is at 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. Assuming that a farmer i uses traditional inputs X to produce single or multiple conventional outputs 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. However, if markets are imperfect, farmers' yields can be pulled below the production frontier.

Moreover, some environmentally detrimental inputs can be introduced in the function production[13]. In this case, a farmer needs to maximize his conventional desirable outputs with the set of environmental inputs as well as with its conventional inputs (X).

In this context, we follow Reinhard et al. (1999) by stating EE as the ratio of minimum feasibility to observed use of environmentally detrimental inputs, conditional to observed levels of output and conventional inputs[14]. This can be formulated by the following non–radial input–oriented measure:

$$EE_i(x, y) = [\min \theta : F(x_i, \theta Z_i) \geq y_i], \tag{1}$$

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

Within the framework developed by Reinhard et al. (1999), EE can be calculated using

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

[14] Environmental efficiency is thus an input–oriented measure, i.e., less environmental detrimental inputs with the same output and conventional inputs.

a standard translog production function as follows (Christensen et al., 1971)[15]:

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

where $i = 1, \ldots, n$ are the farmer unit observations and $t = 1, \ldots, T$ are the number of periods; $j, k = 1, 2, \ldots, m$ 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 by the i^{th} individual; $ln(Z_{i,t})$ is the logarithm of the environmental detrimental input applied by the i^{th} individual; and β_j, β_z, β_{jk}, β_{jz} and β_{zz} are parameters to be estimated[16]. The logarithm of the output of a technically efficient producer $Y^F_{i,t}$ with $X_{i,t}$ and $Z_{i,t}$ can be obtained by setting $U_{i,t} = 0$ in Equation 2. However, the logarithm of the output of an environmentally efficient producer $Y_{i,t}$ with $X_{i,t}$ and $Z_{i,t}$ is obtained by replacing $Z_{i,t}$ by $Z^F_{i,t}$, where $Z^F_{i,t} = EE_{i,t} * Z_{i,t}$, and setting $U_{i,t} = 0$ in Equation 2 as follows

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

The logarithm of EE ($lnEE_{i,t} = lnZ^F_{i,t} - lnZ_{i,t}$) can now be calculated by setting Equations 2 and 3 equal as follows:

$$\frac{1}{2}\beta_{zz}(lnEE_{i,t})^2 + (lnEE_{i,t})[\beta_z + \sum_{j=1}^{m} \beta_{jz} lnX_{ij,t} + \beta_{zz} lnZ_{i,t}] + U_{i,t} = 0, \tag{4}$$

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

[16] 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.

By solving Equation4, we obtain:

$$lnEE_{i,t} = \left[- \left(\overbrace{\beta_z + \sum_{j=1}^{m} \beta_{jz} lnX_{ij,t} + \beta_{zz} lnZ_{i,t}}^{A} \right) \pm \left\{ \left(\overbrace{\beta_z + \sum_{j=1}^{m} \beta_{jz} lnX_{ij,t} + \beta_{zz} lnZ_{i,t}}^{B} \right) - 2\beta_{zz} U_{i,t} \right\}^{0.5} \right] / \beta_{zz} \tag{5}$$

As mentioned by Reinhard et al. (1999), the output-oriented efficiency is estimated econometrically whereas environmental efficiency (Eq. 4) is calculated from parameter estimates (β_z and β_{zz}) and the estimated error component ($U_{i,t}$).

Since a technically efficient farm ($U_{i,t} = 0$) is necessarily environmentally efficient ($lnEE_{i,t} = 0$). The "$+\sqrt{}$" must be used[17].

In our case of paddy rice production, 3 traditional inputs and 1 environment detrimental input are identified for the production function. The final stochastic model in the translog case is as follows:

$$Output_{k,i,t} = \beta_0 + \beta_1.Labor_{k,i,t} + \beta_2.Capital_{k,i,t} + \beta_3.Water_{k,i,t} + \beta_4.N_{k,i,t} + \beta_5.Labor^2_{k,i,t} + \cdots + \beta_9.Labor_{k,i,t} * Capital_{k,i,t} + \cdots + \sum_{j=1}^{5} Seasons + \sum_{j=1}^{7} SEED - U_{k,i,t} + V_{k,i,t}, \tag{6}$$

where the output is the yield of raw rice, 3 traditional inputs are the labor, capital and water, and the environment detrimental input is N, the pure nitrogen input(both organic and chemical source), *Seasons* is a dummy fixing each of the five crop seasons and *SEED* is a dummy variable for the type of species of rice.(see Tables 2 and 8 for descriptive statistics, and Table 7 for description and definition of variables). The ineffi-

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

ciency term is allowed to be time–variant following the Battese–Coelli parametrization of time-effects (Battese and Coelli, 1992). Therefore, the maximum likelihood estimator is used to estimate TE, which is modeled as a truncated-normal random variable multiplied by a specific function of time[18].

The standard model above assumes that there is a common technology in the paddy rice production. However, the organic standards and the different environment conditions could probably make the shape of technology different between organic and conventional farming systems. Should we explicitly address this technological heterogeneity in the production function? Two conflicting points of view exist in the efficiency measurement literature regarding the way that the issue of technology and environment conditions should be addressed. The first approach highlights the importance of differences in the technologies and suggests that different technologies and environmental factors should be included directly into the production function (Good et al., 1992) or addressed alternatively by means of latent class models (Greene, 2005). The second approach assumes the technology and environmental factors influence the degree of technical inefficiency so that these factors could be included in the inefficiency term (Battese and Coelli, 1995). To this effect, a two-stages analysis is relevant to take into consideration of this heterogeneity of technology and environment. Actually, both points of view appear reasonable depending upon ones philosophical perspective and research objective. In this case study we adopt the second approach for two reasons: (1) according to our previous analysis in section 2, the technical differences between organic and conventional farming are non-significant in a small environment such as Sancha village; (2) the second approach allows comparing directly other than separately the organic and conventional systems in terms of TE and EE. This corresponds better to our research objective to understand the sustainability of organic farming with respect to conventional farming. With a two-stages analysis approach, we calculate the TE and EE under the hypothesis of homogeneous technology for organic and conventional farming in the first stage, and then we address the differences in terms of EE as well as the selection problem of organic farming in the second stage analysis. To which we will now turn.

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[18] Estimations are made using Stata 11 and the command *xtfrontier*.

3.2 Estimating the effect of organic farming on EE

The second step of analysis consists in comparing organic farming and conventional farming in terms of EE which is calculated from the first step. Here, we use the standard econometric estimation to control for other factors that might determine the EE. The regression equation is as follows:

$$EE_{k,i,t} = \gamma_0 + \gamma_1 Organic_{k,i,t} + \sum_{j=1}^{8} \gamma_{jz} X_{k,i,t} + \sum_{j=1}^{5} Seasons + \sum_{j=1}^{7} SEED + \varepsilon_{k,i,t}, \tag{7}$$

which represents the relationship between EE and organic farming of plot k for farmer i. Here, $X_{k,i,t}$ is a matrix of explanatory variables that are expected to determine EE, i.e., age, sex, education level of household head, and area, geographical environment and soil quality of the plot. Since farmers use different seeds in different seasons according to climate, we need to control for this in the equation with $Seasons$ as a dummy fixing one of the five seasons and $SEED$ as a dummy for different seed species.$\varepsilon_{k,i,t}$ is the error term. The regression of Equation 7 will be made by four estimators. The first is the OLS estimator and provides a "naive" estimation without taking into account (1) the presence of unobserved and time–invariant individual effects, and (2) the endogeneity of organic farming. To deal with the first problem, the "Within" estimator is used whereas the "2SLS" estimator will treat the second problem. We use 2 excluded instruments, the presence of chemical fertilizer pollution near the plot and the geographical distance from farmer's house to the plot. On one hand, the presence of chemical fertilizer pollution near the plot will render organic farming non credible and thus discourage this practice. On the other hand, organic farming requires much more labor due to transport and application of organic compost and manure[19], long distance from house to plot will thus generate a high cost and discourage organic farming[20]. The validity of these instruments is checked by the

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[19] The volume and weight of organic compost and manure are much greater than chemical fertilizer for the same quantity of N.

[20] Since Sancha is a mountainous village, the geographical distance is more suitable to measure with a subjective evaluation by the farmer. See Table 7 for more information on these two instrumental variables.

Sargan over-identification test whereas their power is analysed by both the Shea partial R2 and the F statistics of excluded instruments. Finally, combined with the fixed effect and instrumentation, a “Within-2SLS” estimator allows for consideration of two issues that hinder the consistency of estimation.

Further more, we attempt to explore the heterogenous effect of organic farming on different N input level. Given the endogeneity of N input, we could not introduce this variable and the interactive term to the model directly. Alternatively, we divided the total sample into three equal sub–samples according to three critical levels of N application: (1) a high sub–sample which contains one third of the plots under which the N input is the highest (ln N > 3.42); (2) a low sub–sample of one third of the plots under which the N input is the lowest (ln N < 3.20); (3) a medium sub–sample of one third of the plots between the two levels (ln N between 3.20 and 3.42). Equation 7 is then estimated with respect to each of the three sub–samples. We note that this alternative solution is not perfect, from which we can only observe a correlation other than a causal heterogenous effect. In other words, we are not sure about the explanation of this observed heterogeneity. For the sake of paper scope, we will leave this question for future studies.

Second, as mentioned in section 2, the development of the organic project in Sancha village allows us to explore the variation of EE over time. Promoted by the NGO, the organic project in Sancha village has scaled up since 2009. Along with this scaling up, a boost of N use has been observed in organic farming. This observation inspires the intuition that EE of organic farming may also be different before and after 2009. To this effect, we use the following equation:

$$\begin{aligned} EE_{k,i,t} = \alpha_0 + \alpha_1 Organic_{k,i,t} + \alpha_2 2009_{k,i,t} + \alpha_3 2009 * Organic_{k,i,t} + \sum_{j=1}^{9} \alpha_{jz} X_{k,i,t} \\ + \sum_{j=1}^{5} Seasons + \sum_{j=1}^{7} SEED + \varepsilon_{k,i,t}, \end{aligned} \tag{8}$$

Where the variable 2009 is a dummy of 1 if the season is in 2009 or after and 0 if the season is before 2009[21]. The variable $2009 * Organic$ is an interactive term which captures the difference of organic effects before and after 2009. $X_{k,i,t}$ is the same matrix of explanatory variables as in Equation 7. $Seasons$ and $SEED$ control for different crop seasons and rice species respectively, and $\varepsilon_{k,i,t}$ is the error term. Here, we apply a step-by-step analysis by adding successively to the basic regression the dummy variable 2009 and the interaction term $organic * 2009$. For the estimation, the same four estimators (OLS, Within, 2SLS and Within-2SLS) is applied to correct for the endogeneity problem of organic farming and obtain consistent estimates.

4 Data and descriptive statistics

The data used for this study derived from a detailed survey conducted in Sancha village by one of authors. For purpose of comparative study, 2 plots(one organic and one conventional) were randomly selected for every active farmers from their reported paddy fields, information about the rice production was then collected on basis of the plot[22]. To ensure the reliability of organic practice reported by farmers, we also check the answers with the record of the farmers' association. Inconsistent answers were dropped from the dataset. Information is collected for the past five consecutive crops seasons (from 2008 to first half of 2010) with respect to output and inputs used on the plot. The output consists of raw rice yield reported by farmers and expressed as kg/mu. Labor, capital and water are identified as three major conventional inputs and pure N as environmentally detrimental input for paddy rice production. For labor use, we asked farmers for labor time spent on each segment of a given rice production cycle, such as soil plowing, plant setting, composting, fertilizer application, weed and pest control and harvesting. The final labor use is the sum of all segments and measured as hours/mu. "Capital" refers to financial expenditures on machine use during the entire production cycle and it is measured as yuan/mu. To calculate N input, we use the experimentation data of nitrogen content provided by local agronomists and farmers' self–reporting of nutrient inputs. The calculation is the same

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[21] Note that there are five seasons from 2008 to the first season of 2010.

[22] Farmers with no organic plots were asked to give information on 2 conventional plots.

as performed in Section 2[23], and is expressed as kg/mu. While water use is important for paddy rice production, it is also difficult to quantify. Given the lack of irrigation infrastructure, water consumption is expected to be constrained by water availability to the plot. We hereby construct a proxy variable, namely the index of water availability, which relies on average rain fall and mice activity on the plot observed by farmers. For the explanatory variables, socio–economic characteristics of households are collected. These characteristics include the age, sex and education level of the head of household. We also collected information on plot characteristics such as area, geographical environment, soil quality, geographical distance and nearby presence of fertilizer pollution spots. Table 2 gives descriptive statistics of the database and a summary of variable definitions can be found in Table 7.

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[23] The nutrient inputs 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)		Conv Plot(667)		Equality test
	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 (1-3)	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 environment (0/1)	0.25	(0.07)	0.12	(0.01)	0.3	(0.1)	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 the descriptive statistics, we note that organic farming is more labor intensive than conventional farming, which is explained by the additional work of compost fabrication and transportation, as well as farm management. Combined with the age difference between organic farming and conventional farming, it is reasonable to identify the labor force shortage as one of the greatest constraints for organic farming development in rural China. However, it appears true that organic farming has absorbed more female labor than conventional farming. For other factors that distinguish organic from conventional farming, we note that most organic plots are well situated (in open cultivated zones), of good soil quality and less distant from farmers' houses. Finally, the influence of neighbor fertilizer pollution is much more significant for conventional farming than for organic farming. In the following section, we will present the calculated EE from this data, as well as the main results of our empirical estimations.

5 Results and discussion

5.1 The calculated EE from an SFA model

Before turning to the second step of the study which attempts to determine the effect of organic farming on EE, we need firstly check the relevance of the SFA model and the significance of TE in table 3.

Table 3: Stochastic production frontier model

Dependent variable: rice output				
			Input elasticities	
	(1)	(2)	(3)	(4)
Variables	Coefficient estimate	Standard error	Sample mean	Sample median
Labor	0.844^{*}	0.467	-0.019	-0.044
Capital	1.328^{***}	0.183	0.083	0.128
Water	1.030^{***}	0.388	0.132	0.159
N	0.216	0.447	0.360	0.321
Labor squared	$-.086^{*}$	0.045		
Capital squared	$-.164^{***}$	0.016		
Water squared	0.077	0.058		
N squared	-.022	0.067		
Labor*Capital	-.018	0.035		
Labor*Water	$-.120^{*}$	0.062		
Labor*N	0.043	0.068		
Capital*Water	0.0007	0.031		
Capital*N	0.051	0.036		
Water*N	$-.142^{*}$	0.073		
Intercept	0.63	1.460		
Observations	1,012			
♯ plot	203			
χ^2 statistic	761.16			
Log-likelihood	259.352			
Sig-u (TE.)	0.212			
Sig-v (errors.)	0.151			
$H_0 : \mu = 0$	0.270^{***}			
$H_0 : \eta = 0$	0.034^{*}			
$H_0 : \gamma = 0$	0.683^{**}			

Estimation method: Maximum likelihood estimator with time-variant TE. $H_0 : \mu = 0$, $H_0 : \eta = 0$ 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. 5 seasons and 7 seeds are controlled for. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Firstly, we check the theoretical consistency of our estimated efficiency model by verifying that the marginal productivity of inputs are positive. In other words, if this theoretical criterion is empirically checked, then the obtained efficiency estimates can be considered as consistent with microeconomics theory. As the coefficients of the translog functional form do not allow for 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 (3))[24].

In our sample, the paddy rice production in Sancha village depends more strongly on N input (0.36) and water (0.13) at sample mean. This suggests that yield of rice production is most likely relative to N input and water use. However, the marginal productivity of labor appears to be negative (-0.019) at sample mean. This result seems to be relevant within the context of Chinese agriculture, according to 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 must be very low, even negative in some cases (Tian and Wan, 2000; Tan et al., 2010; Chen et al., 2006). Finally, our results ensured that the returns to scale at sample mean and sample median are both positive, proving that the production technology and inputs used are relevant to estimate TE.

Within the framework of the translog stochastic production frontier, we predict TE and thereby calculate EE (see Table 8 regarding descriptive statistics of TE and EE). TE is significant in our sample with a mean value of 0.73, ranging from 0.33 to 0.98. The score suggests that most farmers, both conventional and organic, have sufficiently mastered the technology to produce satisfactory yield. However, when looking into the EE score, the mean value is only 0.45, ranging from 0.08 to 0.96. The standard error of EE is higher (0.18) than that of TE (0.12). This result suggests that most farmers are not

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[24] The coefficients estimated in the translog specification are not the input's elasticity and so the result cannot be directly 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 mean of the log of the input variable and its second order coefficients as follows:

$$\frac{\delta lnY}{\delta X_j} = \beta_j + 2.\beta_{jj}\overline{lnX_j} + \Sigma_{j\neq k}^{K}\beta_{jk}\overline{lnX_k}. \tag{9}$$

environmentally efficient and, thus, TE cannot guarantee EE. To investigate the effect of organic farming on EE, we will now turn to the second step of our analysis.

5.2 Environmental performance of organic farming

5.2.1 Organic farming vs conventional farming

Table 4 presents the main results of our estimation. To save space, we report here only results using Within and Within-2SLS estimator for total sample as well as three sub-samples. For more thoroughness, Table 9 (see Appendix) reports the results of OLS and 2SLS, and Table 11 (see Appendix) gives the first stage regressions of both 2SLS and Within 2SLS.

Table 4: Organic farming, N input and EE

Dependent variable: EE								
	Within estimator				2SLS-Within estimator			
	(1) (total)	(2) (high)	(3) (med)	(4) (low)	(5) (total)	(6) (high)	(7) (med)	(8) (low)
Organic	0.007*	-0.006	0.02***	0.003	0.002	-0.014	0.03**	0.01
	(0.004)	(0.012)	(0.007)	(0.007)	(0.007)	(0.018)	(0.015)	(0.012)
Age	0.017***	0.019***	0.018***	0.013***	0.017***	0.019***	0.017***	0.012***
	(0.001)	(0.002)	(0.002)	(0.004)	(0.001)	(0.002)	(0.002)	(0.004)
Observations	1012	338	340	334	1012	338	340	334
♯ plots	203	117	146	130	203	93	110	101
Adjusted R2	0.388	0.391	0.465	0.386	0.232	0.123	0.143	0.067
F statistic	82.496	25.245	37.477	28.204	91.173	29.135	29.59	25.099
RMSE	0.021	0.018	0.014	0.017	0.023	0.022	0.019	0.022

Note: Robust standard errors in parentheses. Columns 1–4 report results with the Within estimator, Columns 5–8 report results with the 2SLS-Within estimator. Area, sex, education, geography and soil quality are time invariant variables. 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Generally speaking, the difference of EE between organic and conventional farming is very small or non-significant (Col.1 and Col.5). But when looking closer, things are different for different sub-samples. For the low sub-sample (where the N application rate is below 12.27kg/Mu), the sign of organic farming is positive but not significant. There is actually no significant difference between organic and conventional farming on low input level. For the medium sub-sample (where the N application rate is between 12.27kg/Mu and 15.29kg/Mu), the sign of organic farming is significantly positive. At this level of input, the EE of organic farming is higher compared to conventional farming. Curiously, on high N input levels (where the N application rate is above 15.29kg/Mu), the effect of organic farming becomes negative but non–significant. The level of EE becomes again non-significant between organic and conventional farming for farmers who use high N input. As one can note, the correction for endogeneity problem of Organic with instrumentation does not change these results. They remain consistent. These empirical results provide evidence that, *a priori*, organic farming is more environmentally efficient than conventional farming, but this advantage is not stable, it can decrease to zero for farmers who are at high level of N input. That's why we can only observe very small or non-significant difference in the total sample.

5.2.2 Variation of EE over time

We recall that in Section 2, a boost of N input for organic farming is observed coupled with the scale-up period after 2009. If our results are true, it is also true that the EE of organic farming is decreasing after 2009. To check the robustness of our results, we now turn to the variation of EE over time.

Table 5: Differential time effect of organic farming on EE

Dependent variable: EE	Within estimator			2SLS-Within estimator		
	(1)	(2)	(3)	(4)	(5)	(6)
Organic	0.013*** (0.004)	0.009** (0.004)	0.014*** (0.005)	0.01 (0.008)	0.005 (0.008)	0.015* (0.008)
2009		0.018*** (0.003)	0.02*** (0.003)		0.019*** (0.003)	0.022*** (0.004)
2009*Organic			-0.007* (0.004)			-0.012** (0.005)
Age	0.015*** (0.001)	0.004** (0.002)	0.004** (0.002)	0.015*** (0.001)	0.004* (0.002)	0.004* (0.002)
Observations	1012	1012	1012	1012	1012	1012
♯ plots	203	203	203	203	203	203
F statistic	77.181	82.269	69.485	82.262	74.649	59.66
Adjusted R2	0.252	0.278	0.28	0.252	0.277	0.279
RMSE	0.023	0.022	0.022	0.026	0.025	0.025
Hansen statistic				0	0	0.332
Hansen p-value						0.565

Note: Robust standard errors in parentheses. Columns 1–3 report results with the Within estimator, Columns 4–6 report results with the 2SLS-Within estimator. Area, sex, education, geography and soil quality are invariant variables. In columns 4–5, the Hansen statistics is zero since there is only one IV (distance is time invariant). 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 5 presents the result of EE before and after 2009, the year when the organic farming project scaled up. To save space, we just present here the results of Within and Within-2SLS estimators. A full report of OLS and 2SLS results as well as its first stage regressions can be found respectively in Table 10 and Table 11 (see Appendix).

In column 6 of Table 5, organic farming was found to have a positive and significant effect after controlling for (1) the individual fixed effects and (2) the dummy variable 2009. However, the interaction term has a significant and negative effect (except for the 2SLS estimator; however, the sign is negative), that is to say, all things equal, organic farming was more environmentally efficient than conventional farming before 2009, while after 2009, EE of organic farming significantly decreased. After correcting for the endogeneity problem with IV method, our result remains consistent and robust (see column 12). This has in turn confirmed our precedent results.

Our empirical results need to be interpreted with caution, they shed light on the potential risk of sustainability for organic farming in poor rural areas, and help to understand the crucial conditions to increase its performance in terms of EE. The correlation between the N input level and decreasing performance of organic farming indicates risk of policy like organic fertilizer subsidy. It seems to be inappropriate since it may encourage the N use which is related to low environmental efficiency of organic farming. Actually, the sustainability of organic farming relies more on efficient nutrient cycling within the agro–ecosystem than on the external nutrient supply. The aim of nutrient application is thus to improve and enhance the fertility and resilience of soil, but not to feed the plant directly. Substitution of chemical nutrients with organic nutrient is a first step but not sufficient to achieve this goal. Additional efforts are required on the control of nutrient application levels. Therefore, more technical support and strict regulation is more appropriate for a sustainable development of organic farming. Being conscious of that, the Chinese government is revising its national policy of organic farming at the moment of this paper. New and more precise standards will be published in the near future.

However, this study does not investigate the underlying mechanism behind the decreasing performance of organic farming along with the N input level. First of all, there may be structural mechanisms if significant differences lie between technologies of organic and conventional farming. According to agronomist observations, the yield of organic farming is less sensitive to N input over certain critical levels (Kirchmann and Ryan, 2004). On the contrary, excessive use of organic nutrients is harmful to crops and eventually reduces output. This hypothesis will need more support from long-term experimental agronomic studies, but if this is the case, organic farmers with high N input may have surpassed the critical level and found significant reduction in their yields and EE. On the other hand, there may be institutional explanations. As mentioned in Section 2, for newly converted farmers, the lack of experience and fear of loss from conversion will drive them to use more N input, while these characteristics can also reduce their EE. This phenomenon may be specific to the period of transition. If this is the case, more institutional support (e.g., training and extension services) is required to reinforce farmers' capacity and help them to overcome this transitional period. Alternatively, social mechanisms can also be explored to improve the environmental performance of organic farming. There is a large room for the future studies.

Finally, our study seems to be more favorable for smallholder organic farming in developing countries where the nutrient input is generally low. In light of growing trends that see development agencies and enterprises seeking to expand and industrialize organic farming in developing countries, our study warns of the potential risk of excessive expansion, and thus the need for regulation of nutrient use and input in organic system.

6 Concluding remarks

Emerging as a paradigm of a sustainable agriculture system, organic farming was originally sought to preserve the agricultural environment. However, from an economic point of view, organic farming should also maintain adequate yield. In this case study, we attempt to investigate the sustainability of organic farming in China using the indicator, environmental efficiency (EE), which takes account of both yield and environmental preservation. Under the framework of SFA, we calculate EE for paddy rice production in a small village in China. Our econometric approach has significant advantages compared to conventional measures of N-use efficiency, as we have taken into consideration natural shock as well as interaction with other productive inputs, e.g., labor, capital and water when calculating N-use efficiency. Our empirical results demonstrate that organic farming could lose its advantage of EE in the process of scaling up due to the overuse of N. This result is in line with the results from agronomist experiments which have indicated that the N-use efficiency is lower for organic system than conventional system in Europe (Kirchmann and Ryan, 2004; Lundstrom and Linden, 2001). Our results suggest that to maintain the sustainability of organic farming in developing countries, development agencies should replace organic fertilizer subsidies by more technical support, slow down the expansion of organic farming and make strong efforts to control the use of external nutrients.

As a preliminary study, we note several limitations of present study. First of all, if data were available, we would take into consideration more aspects than quantity of pure nitrogen input (i.e., N loss to environment) to calculate EE. Broadly speaking, organic farming has positive environmental impact compared to conventional farming in terms of a higher level of organic matter in the soil and ecological diversity. While this improvement will certainly have impact on productivity in the long run, the effects cannot be observed within five crop seasons. We will need data of longer period to evaluate the potential EE of organic farming in a long run.

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7 Appendix

7.1 Location of Sancha village

Source: www.map-of-china.org

7.2 Definition of variables and descriptive statistics

Table 7: 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 "jin/mu".
Labor	Hours spent in paddy rice production on the plot. It is weighted by the age of farmer. The unit is "hours/mu".
N	The external Nitrogen input from organic source or inorganic source for the paddy rice production on the plot. The unit is "jin/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 1 to 3. 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	Years of education of the household head.
Geography	The geographical environment of plot with "1" in mountains enclosed zone and "0" in open 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 nearby the plot: "1" for yes and "0" for no.
Seed	Seven different species of rice seeds cultivated by farmers during the 5 seasons coded from 1 to 7.

Table 8: Descriptive Statistics

Variables	Mean	Standard deviation	Min	Max	♯ obs.
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.

7.3 Results of OLS and 2SLS estimators

Table 9: Organic farming, N input and EE

Dependent variable: EE								
	OLS estimator				2SLS estimator			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(total)	(high)	(med)	(low)	(total)	(high)	(med)	(low)
Organic	-.010	-.100***	0.026	0.045*	-.003	-.090**	-.014	0.101*
	(0.015)	(0.024)	(0.027)	(0.026)	(0.027)	(0.042)	(0.043)	(0.053)
Area	-.179***	-.377***	-.194***	-.082*	-.180***	-.377***	-.188***	-.095**
	(0.03)	(0.061)	(0.055)	(0.043)	(0.03)	(0.06)	(0.054)	(0.043)
Age	-.002***	-.003***	-.001*	-.001	-.002***	-.003***	-.002**	-.001
	(0.0005)	(0.0009)	(0.0008)	(0.0008)	(0.0005)	(0.0009)	(0.0007)	(0.0008)
Sex	-.011	-.053**	0.0007	0.002	-.012	-.054**	0.006	-.002
	(0.013)	(0.023)	(0.022)	(0.02)	(0.013)	(0.023)	(0.022)	(0.02)
Education	-.004**	-.005*	-.006*	-.006*	-.004**	-.005*	-.006*	-.007*
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
Geography	-.042**	0.016	-.047	-.053	-.041**	0.018	-.055	-.045
	(0.02)	(0.036)	(0.039)	(0.033)	(0.021)	(0.035)	(0.038)	(0.035)
Soil quality	0.03***	0.072***	0.011	0.017	0.029***	0.071***	0.018	0.008
	(0.009)	(0.017)	(0.016)	(0.012)	(0.009)	(0.016)	(0.017)	(0.015)
Intercept	0.53***	0.577***	0.566***	0.497***	0.532***	0.578***	0.549***	0.515***
	(0.039)	(0.067)	(0.072)	(0.065)	(0.04)	(0.067)	(0.073)	(0.066)
Observations	1012	338	340	334	1012	338	340	334
♯ plots	203	117	146	130	203	93	110	101
Adjusted R2	0.077	0.207	0.054	0.044	0.077	0.206	0.048	0.027
F statistic	9.545	10.394	2.942	2.978	9.541	9.906	3.227	2.871
RMSE	0.182	0.183	0.187	0.164	0.181	0.179	0.184	0.162
Hansen stat.					4.243	3.874	0.16	0.926
Hansen p-val.					0.039	0.049	0.69	0.336

Note: OLS robust standard errors in parentheses. Columns 1–4 report results with the OLS estimator, Columns 5–8 report results with the 2SLS estimator. 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 10: Differential time effect of organic farming on EE

Dependent variable: EE						
	OLS estimator			2SLS estimator		
	(1)	(2)	(3)	(4)	(5)	(6)
Organic	-.004	-.006	0.026	0.004	-.0009	0.022
	(0.015)	(0.015)	(0.026)	(0.026)	(0.027)	(0.047)
2009		0.023*	0.039***		0.024*	0.033*
		(0.012)	(0.014)		(0.013)	(0.017)
2009*Organic			-.049*			-.031
			(0.029)			(0.048)
Area	-.180***	-.191***	-.176***	-.181***	-.181***	-.179***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Age	-.002***		-.002***	-.002***	-.002***	-.002***
	(0.0005)		(0.0005)	(0.0005)	(0.0005)	(0.0005)
Sex	-.012	-.002	-.010	-.013	-.012	-.012
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Education	-.004**	-.002	-.004**	-.004**	-.004**	-.004**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Geography	-.041**	-.039*	-.044**	-.039*	-.041**	-.041**
	(0.021)	(0.02)	(0.021)	(0.021)	(0.021)	(0.021)
Soil quality	0.029***	0.032***	0.031***	0.028***	0.029***	0.029***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Intercept	0.554***	0.438***	0.533***	0.555***	0.544***	0.538***
	(0.038)	(0.026)	(0.039)	(0.038)	(0.039)	(0.039)
Observations	1012	1012	1012	1012	1012	1012
♯ plots	203	203	203	203	203	203
F statistic	13.039	12.134	11.3	13.025	12.176	10.975
Adjusted R2	0.081	0.075	0.088	0.081	0.085	0.087
RMSE	0.182	0.183	0.182	0.182	0.181	0.181

Note: Robust standard errors in parentheses. Columns 1–3 report results with the OLS estimator, Columns 4–6 report results with the 2SLS estimator. 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

7.4 First–stage regressions results (IV)

Table 11: First stage regressions of Table 5

Depend Variable	Organic	Organic	Organic	2009*Organic	Organic	Organic	Organic	2009*Organic
Col. Table 5	col.7	col.8	col.9	col.9	col.10	col.11	col.12	col.12
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Excluded instruments								
Distance	-.044***	-.046***	-.024	0.02*				
	(0.014)	(0.014)	(0.016)	(0.011)				
Chemicals influence	-.564***	-.555***	-.622***	0.436***	-.604***	-.586***	-.629***	0.489***
	(0.031)	(0.031)	(0.055)	(0.05)	(0.067)	(0.066)	(0.077)	(0.097)
2009*distance			0.029*	-.055***			-.012	-.050**
			(0.015)	(0.013)			(0.019)	(0.025)
2009*chemicals influence			0.614***	-.656***			0.4***	-.667***
			(0.056)	(0.038)			(0.085)	(0.069)
Included instruments								
Organic				0.652***				0.702***
				(0.034)				(0.06)
2009		0.063***	-.785***	0.91***		0.111***	-.384***	0.901***
		(0.022)	(0.052)	(0.035)		(0.032)	(0.091)	(0.069)
2009*organic			0.938***				0.569***	
			(0.012)				(0.068)	
Area	0.056	0.054	-.027	0.051**				
	(0.046)	(0.046)	(0.032)	(0.025)				
Age	-.002***	-.003***	-.0007	-.0003	0.042***	-.023	-.011	-.001
	(0.0009)	(0.0009)	(0.0005)	(0.0004)	(0.012)	(0.018)	(0.008)	(0.007)
Sex	0.102***	0.103***	0.032**	0.009				
	(0.024)	(0.024)	(0.014)	(0.012)				
Education	0.007*	0.007*	0.002	0.0009				
	(0.004)	(0.004)	(0.003)	(0.002)				
Geography	-.017	-.018	0.005	-.013				
	(0.04)	(0.04)	(0.025)	(0.02)				
Soil quality	0.059***	0.061***	0.023**	0.0007				
	(0.015)	(0.015)	(0.01)	(0.008)				
Intercept	0.632***	0.597***	0.728***	-.559***	-1.550**	1.916**	1.301***	-.494
	(0.087)	(0.088)	(0.073)	(0.062)	(0.644)	(0.955)	(0.453)	(0.415)
Observations	1012	1012	1012	1012	1012	1012	1012	1012
♯ Plots	203	203	203	203	203	203	203	203
F statistic	304.579	281.835	4428.508	1737.079	57.384	44.698	50.25	339.573
R^2	0.54	0.544	0.824	0.854	0.426	0.438	0.671	0.787
Adjusted R2	0.536	0.539	0.821	0.852	0.424	0.436	0.668	0.786
RMSE	0.323	0.322	0.2	0.167	0.18	0.178	0.136	0.151
Shea Partial R2	0.34	0.34	0.34	0.40	0.30	0.28	0.30	0.41
F statistic–excluded IV	192.57	184.23	98.69	177.26	170.26	164.84	87.05	233.47

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. Area, sex, education, geography and soil quality are invariant variables. 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.

Table 12: First stage regressions of Table 4

Depend Variable Col. Table 4	Organic col.9	Organic col.10	Organic col.11	Organic col.12	Organic col.13	Organic col.14	Organic col.15	Organic col.16
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Excluded IV								
Distance	-.045***	-.044*	-.026	-.060**				
	(0.014)	(0.024)	(0.023)	(0.026)				
Chemicals influence	-.550***	-.567***	-.609***	-.494***	-.585***	-.573***	-.420***	-.638***
	(0.031)	(0.051)	(0.05)	(0.061)	(0.066)	(0.147)	(0.137)	(0.113)
Area	0.06	0.043	0.064	0.081				
	(0.046)	(0.102)	(0.073)	(0.083)				
Age	-.002***	0.0005	-.003*	-.004**	0.038***	-.015	0.032**	0.018
	(0.0009)	(0.002)	(0.001)	(0.002)	(0.011)	(0.013)	(0.015)	(0.015)
Sex	0.101***	0.104**	0.103***	0.104**				
	(0.024)	(0.043)	(0.036)	(0.042)				
Education	0.007*	0.012*	-.002	0.016**				
	(0.004)	(0.007)	(0.006)	(0.008)				
Geography	-.018	-.062	-.080	0.031				
	(0.04)	(0.055)	(0.059)	(0.087)				
Soil quality	0.06***	0.006	0.073***	0.08***				
	(0.015)	(0.028)	(0.027)	(0.025)				
Intercept	0.559***	0.49***	0.551***	0.629***	-1.365**	1.568**	-1.199	-.179
	(0.09)	(0.159)	(0.163)	(0.152)	(0.598)	(0.746)	(0.824)	(0.804)
Observations	1012	338	340	334	1012	338	340	334
♯ plots	203	117	146	130	203	117	146	130
F statistic	223.702	89.606	116.715	68.053	31.685	3.98	3.776	12.994
Adjusted R2	0.542	0.563	0.611	0.458	0.436	0.392	0.314	0.485
RMSE	0.321	0.319	0.298	0.339	0.178	0.11	0.118	0.123
Shea Partial R2	0.33	0.36	0.41	0.25	0.28	0.37	0.19	0.39
F statistic–excluded IV	178.30	68.31	77.20	41.41	163.69	23.68	10.47	36.86

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. Area, sex, education, geography and soil quality are invariant variables. 5 seasons and 7 seeds are controlled for all estimators. *** statistical significance at 1%, ** statistical significance at 5%, * statistical significance at 10%.