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Inaccurate fertilizer content and its effect on the estimation of production functions☆

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ABSTRACT

Discrepancy between the labeled content and the real content of fertilizer is a growing problem. It exists in many countries, such as Bangladesh, Cambodia, China, Nigeria, Tanzania, Vietnam, and more. We analyze in our article the effect of low quality fertilizer, which contains less nitrogen than is advertised on the packaging. We show that this could lead to bias in the estimation of production functions. Using panel data from the Hebei Province of China and the Monte Carlo simulation, we examine the magnitude of the bias across different levels of fertilizer quality under various scenarios of uncertainty. We find that ignoring the uncertainty leads to an overestimation of fertilizer's effectiveness. Depending on the scenarios of uncertainty, the bias could even switch the sign of fertilizer's partial elasticity.

1. Introduction

Rising food prices push farmers to increase agricultural output, and given the existing land constraints, much of this is achieved by applying more farm inputs (Fuglie, 2010; Wik, Pingali, & Broca, 2008). A question that follows is whether this increase in input use is actually beneficial. An example is the overuse of chemical fertilizer that leads to problems such as a rise in the deposition of atmospheric nitrogen that degrades both the land and water ecosystems (He, Liu, Fangmeier, & Zhang, 2007; Liu et al., 2013; You, Spoor, Ulimwengu, & Zhang, 2011), and nitrate leaching into groundwater (Chen, Tang, Sakura, Yu, & Fukushima, 2005; Wan et al., 2009) that pollutes the main water sources for many different uses including drinking water (Hu et al., 2005; Jiang & Jiang, 2013).

The primary focuses of socioeconomic studies of fertilizer use are on application level and determining factors (Babcock & Hennessy, 1996; Lamb, 2003; Ye & Rozelle, 1994), the contribution of fertilizer to productivity growth (Chen, Huffman, & Rozelle, 2003; Wang, Halbrendt, & Johnson, 1996; Wong, 1989), its efficiency (Fernandez, Koop, & Steel, 2002; Reinhard, Lovell, & Thijssen, 1999), and its effects on changing production risks (Battese, Rambaldi, & Wan, 1997; Kumbhakar, 1993; SriRamaratnam, Bessler, Rister, Matocha, & Novak, 1987). Babcock (1992) examines how the uncertainty of weather and soil fertility affects optimal fertilizer use. To the best of our knowledge, there is no previous study on how quality uncertainty of purchased agricultural inputs affects the estimation of farm production. There have been recent reports of low quality or fake fertilizer in countries such as Bangladesh (Zahur, 2010), Cambodia (Hamaguchi, 2011), China (Han, 2009), Nigeria (Liverpool-Tasie, Olaniyan,

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Salau, & Sackey, 2010), Tanzania (Mwakalebela, 2012), Vietnam (Phien, 2013) and more. In China alone, the value of fake agricultural input reached 23.5 million U.S. dollars in just the first six months of 2011 (Wang, 2011). We incorporate uncertainty in fertilizer content into the estimation of technical efficiency and show that the estimates will be biased if we ignore the quality effect, for example when the real fertilizer content is less than the labeled content on the package. The inaccuracy in this case is of a one-sided nature, which is different from the two-sided variety that usually exists in the analysis of random measurement errors. We focus our analysis on fertilizer because previous studies in our research region by Boeber, Kuehl, and Rumbaur (2009) and Khor and Zeller (2013) show that there is a difference between the true fertilizer content and its labeled content. We are not aware of a similar test being conducted in the same region on seed, other than the general information provided by the news reports. In addition, the effect of fake seed is observable by farmers when there is no maize plant sprouting. The effect of fake fertilizer is less obvious, especially in our research region, because the input is overused and its marginal effect is very low. In an analysis that combines both household survey and fertilizer testing, Khor and Zeller (2013) find that there is no significant correlation between the true quality of fertilizer (based on laboratory testing of fertilizer content) and farmer's perception of fertilizer quality.

We present in our article two different scenarios of uncertainty for fertilizer quality because the distribution of uncertainty depends on the socio-economic structure as well as the number of manufacturers in the market. The first scenario of random uncertainty applies to the situation in which the manufacturers reduce their product content randomly, in order to lower the chances of being detected and deemed a low quality brand by the buyers. In this case, it depends on luck as to which type of fertilizer the farmers get. It is also plausible that awareness of the problem and expectation about the content may differ based on the location of the households. In addition, there might be factors that are household-specific, such as networking for accessing the information and education for processing the information obtained, which determine the type of fertilizer the farmers receive. Therefore, we include a second scenario, household-specific uncertainty, in our analysis.

2. Methodology

We follow the technical efficiency analysis of Aigner, Lovell, and Schmidt (1977). The authors split the error term of a production function into two components: $\epsilon = u + v$, where v is the stochastic component with a normal $N(0, \sigma_v^2)$ distribution and u is the efficiency component, which is made up of the non-positive portion of a normal $N(0, \sigma_u^2)$ distribution. The two error components are assumed to be independent of each other. This approach of stochastic frontier analysis has been a widely used method to examine the technical efficiency of farmers in various parts of the world. Fan (1991) is one of the first to use the stochastic approach to estimate the efficiency of agriculture in China. He finds that chemical fertilizer was a huge factor in the fast agricultural growth up to the 1980s. The impact of fertilizer has however diminished greatly since then due to the overuse of the input. Tian and Wan (2000)show that in the mid 1990s, even though the output elasticity of fertilizer was still quite high in wheat production with a value of 0.3, the impact on maize was very small at 0.035. A long term analysis from Zhou and Turvey (2014) indicates that the output elasticity of fertilizer for maize production in Hebei was quite low at 0.091, despite covering the period from 1979 to 2010, which included the high productivity years of the 1980s. In a review of other studies by Chen et al. (2003), we can see that the marginal effect of fertilizer is quite small or negative, and the latest studies from Zhen, Zoebisch, Chen, and Feng (2006) and Cui et al. (2008) find that nitrogen use is no longer a significant factor in determining marginal crop yield in our research region of the North China Plain.

2.1. Econometric model

A common method used in a production function estimation is the maximum likelihood (ML) approach, in which the efficiency term is part of the total error term, so we need the exogeneity of input use assumption and a distribution assumption for the efficiency term. These two assumptions are not needed if we have panel data and assume that the efficiency term is constant over time (Bravo-Ureta & Pinheiro, 1993). The constant efficiency assumption allows us to use the fixed effects (FE) approach, in which the fixed effects dummy for each household acts as the efficiency term of the individual household. We estimate the production function using both of these methods to show their differences in coefficients. For the analysis on the effect of uncertainty, we focus on the FE approach because it takes the efficiency term, u, out of the total error term. In this case, the use of FE would prevent the endogeneity problem between input use and error term that leads to biased estimates (Schmidt & Sickles, 1984).

Technical efficiency can be estimated as part of a production function (Bravo-Ureta & Evenson, 1994; Keil, Zeller, Wida, Sanim, & Birner, 2008), or a distance function (Bruemmer, Glauben, & Thijssen, 2002), which can be used for the analysis of multiple outputs. As we focus on only one output, we will use the production function approach with a translog functional form:

$$lnY_{it} = \beta_0 + \sum_{j=1}^{4}\beta_j ln\left(X_{jit}\right) + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4}\beta_{jk} ln\left(X_{jit}\right) ln(X_{kit}) + u_i + v_{it}. \quad (1)$$

Y_{it} and X_{it} are the output and input use, respectively, of household i in year t. Following Reinhard et al. (1999), who estimate the production function with labor, capital, variable input, and nitrogen surplus, we include the variables of labor, land, seed, and fertilizer in our production function estimation. Although we focus on these four inputs, the analysis can be easily extended to include more inputs. The term u_i is the fixed effects dummy and captures the technical efficiency of each household. v_{it} is the