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On dealing with the pollution costs in agriculture: A case study of paddy fields

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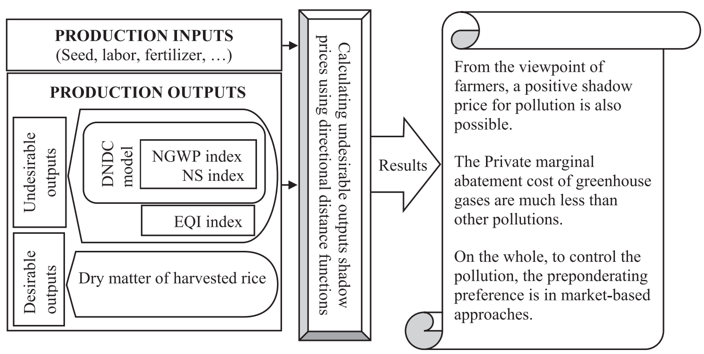
HIGHLIGHTS

- To evaluate agricultural pollution costs, a combination of two DNDC and DEA models was introduced.
- The shadow values of three main agricultural pollutants in paddy fields were evaluated.
- In the study area, a high potential for pollution reduction is feasible.
- The pollution cost of pesticides are much bigger than nitrogen surplus and greenhouse gases.
- From the farmers' viewpoint, a positive shadow value of undesirable outputs also is feasible.
- To deal with the pollution costs, market-based instruments are preferred to command-and-control regulation.

GRAPHICAL ABSTRACT



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ABSTRACT

The main purpose of this study is to evaluate marginal abatement cost of the main agricultural pollutants. In this sense, we construct three indices including Net Global Warming Potential (NGWP) and Nitrogen Surplus (NS), simulated by a biogeochemistry model, and also an Environmental Impact Quotient (EQI) for paddy fields. Then, using a Data Envelopment Analysis (DEA) model, we evaluate environmental inefficiencies and shadow values of these indices. The results show that there is still room for improvement at no extra cost just through a better input management. Besides, enormous potential for pollution reduction in the region is feasible. Moreover, in paddy cultivation, marginal abatement cost of pesticides and herbicides are much bigger than nitrogen surplus and greenhouse gasses. In addition, in the status quo, the mitigation costs are irrelevant to production decisions. Finally, to deal with the private pollution costs, market-based instruments are proved to be better than command-and-control regulation.

1. Introduction

Investigating the environmental impact of undesirable non-marketable productions, e.g., air and soil pollution has been gaining importance in recent years. Although considerable studies have been made on the topic of estimating pollution costs in other sectors

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(e.g., Gao et al., 2016; Hylander and Goodsite, 2006; Morioka et al., 1996), little attention has been given to agriculture so far. Furthermore, those studies that investigated the agricultural pollution costs, did not consider agricultural GHG emissions. In this sense, we also investigate the private marginal abatement cost of GHG emissions. In addition, we consider common agricultural environmental pollutants, i.e., nitrogen surplus and pesticide & herbicides effects, which were taken into consideration by previous studies (Shaik et al., 2002; Lansink and Silva, 2004; Färe et al., 2006; Arandia and Aldanondo-Ochoa, 2011; Dang and Mourougane, 2014; Singbo et al., 2015), Among agricultural activities, paddy fields are one of the largest water, soil and air pollutants (Ahmed et al., 2015; Ghosh and Bhat, 1998; Kou et al., 2015; Wang et al., 2015) and due to the consequences of the ongoing demand for rice, their increasing impact will be inevitable if no action is adopted. Therefore, this study focuses on paddy fields.

To moderate these adverse impacts, some policies should be designed. The questions that arise here are: How can these reductions be achieved in practice? How can policy makers evaluate these pollution costs in agriculture? Is there any possibility to improve environmental conditions, i.e., the reduction of environmental damages, at no extra cost? We try to answer these questions through evaluating technical efficiency and shadow value of agricultural pollutants, from a production technology perspective. In this sense, we consider GHGs emitted from paddy fields (NGWP), Nitrogen Surplus (NS) and Environmental Impact Quotient (EQI) indices as the most important undesirable outputs of paddy fields.

To the authors´ best knowledge, this paper is one of the few studies that addresses the above-mentioned issues in agriculture at the farm level. Because of the sensitivity of marginal abatement cost (i.e., shadow value of pollutions) to the mapping rules, undertaking a very aggregate production function can lead to bias results (Felipe and McCombie, 2014). To evaluate the environmental efficiency and pollution shadow values, we also propose a combination of two biogeochemistry and mathematical programming models. Furthermore, we go into a controversial issue, i.e., the sign of undesirable outputs shadow values. In the absence of regulation, we indicate that shadow value of undesirable outputs can be positive.

The rest of the paper is structured as follows. First, we review the literature from the perspective of production economics. Next, we explain the calculation of nitrogen surplus and GHG emissions of paddy fields. Then, we build a mathematical programming model to address the shadow value of undesirable outputs and environmental efficiency. Afterward, data and empirical results are analyzed. The last part is devoted to conclusion and recommendations.

2. The literature review

In economics, we assess the shadow values of undesirable outputs on the basis of Distance Functions (DF) and duality theory. DFs are divided into radial and non-radial measures. Radial measures are based on the proportionate projection of inputs or outputs on reference frontier. Shephard input and output distance functions are two well-known types of radial measures (Shephard, 1970). These are derived from cost and revenue functions, respectively. The first applications of these measures were Färe et al. (1993) and Hailu and Veeman (2000). To calculate the shadow value of undesirable outputs, Färe et al. (1993) applied a Shephard Output Distance Function (ODF), while Hailu and Veeman (2000) used a Shephard Input Distance Function (IDF). One of the downsides of these measures is that factor productions have an equal and proportional adjustment in the optimization process. Unlike the conventional outputs, undesirable outputs generally have detrimental effects on the environment. However, an ODF cannot properly capture the purpose of decreasing desirable outputs and increasing undesirable outputs at the same time. This is because both desirable and undesirable outputs proportionally change in the same direction. Therefore, it may not capture the real production process. Moreover, applying an IDF to calculate the shadow value of undesirable outputs is not rational. Despite the fact that it decreases desirable outputs and simultaneously increases undesirable outputs, the researcher treats undesirable outputs like inputs, which is not consistent with the economic theory. In this case, the production technology is no longer closed (Färe et al., 2005). A list of the limits for radial measures can be found in Choi et al. (2012).

Non-radial measures have obviated these problems. Most well-known non-radial measures are Slack Based Measures (SBM) and Directional Distance Functions (DDF). Tone (2001) introduced the SBM technology. Five years later, Zhou et al. (2006) incorporated undesirable outputs in Tone's production technology, and Choi et al. (2012) deployed it to calculate the shadow value of undesirable outputs. An SBM, directly deals with the slacks of production factors in a way that both inputs and undesirable outputs decrease while desirable outputs increase. SBMs are better than radial measures in distinguishing efficiency scores. However, unlike radial measures, the scores only provide a ranking among the firms. We can no longer interpret the scores. A DDF is a general form of Shephard distance functions. Unlike ODFs and IDFs, a DDF can be different in the direction of measurement. However, its weakness is that we choose the directional vector arbitrarily. Nevertheless, recently some researchers have attempted to determine directional vectors endogenously (e.g., Hampf and Krüger, 2015).

In practice, there are two parametric and non-parametric approaches to estimate the shadow value of undesirable outputs. Fig. 1 shows a schematic diagram of these approaches.

Parametric approaches are divided into deterministic and stochastic techniques. In deterministic approach, researchers specify the model based on a Translog or a quadratic functional form. Next, by using a deterministic linear programming technique introduced by Aigner and Chu (1968), the shadow value of undesirable outputs is derived from differentiating distance functions and relative market prices. Färe et al. (1993) applied this method for the first time. Other examples of this method are Coggins and Swinton (1996), Färe et al. (2006) and Tang et al. (2016b). In the stochastic approach, the model is specified based on a Translog or a quadratic functional form. Next, researchers estimate the shadow values by a Stochastic Frontier Analysis (SFA) model (Kumbhakar and Lovell, 2003). Examples of this method are Murty and Kumar (2002), Färe et al. (2005) and Van Ha et al. (2008). The deterministic approach does not consider random errors while, the stochastic approach cannot completely satisfy the monotonicity property (Zhou et al., 2014).

A non-parametric approach deploys a Data Envelopment Analysis (DEA) model to calculate the shadow values. In this regard, Boyd et al. (1996) applied a DDF in a non-parametric model to obtain the shadow values in a novel framework. Other examples of this model are Chung et al. (1997), Lee et al. (2002) and Hampf and Krüger (2015). The strengths and weaknesses of these models are as follows: A non-parametric approach is sensitive to outliers. Moreover, it does not provide a relationship among the production factors. Hence, it is not possible to use additional information (e.g., elasticities). However, we do not need to specify a functional form. The inclusion of the pollution in the production process of DEA models is also more realistic (i.e., as undesirable output instead of conventional input) (Hampf and Krüger, 2015). Furthermore, we can calculate considerable of parameters even with a few observations (Van Ha et al., 2008). Besides, non-parametric approaches are flexible and easy to use. As Zhou et al. (2014) concluded, the popularity of non-parametric approaches has increased over time. We also apply a non-parametric approach to estimate the shadow value of undesirable outputs. Our particular contribution is that, in our analysis, we distinguish between farmers and society viewpoints. Besides, to deal with data sensitivity, we make two outlier tests. An important point in our modeling is that undesirable outputs are restricted with an equal sign. Therefore, we deal with both negative and positive shadow values (for more information see Eq. (3) and descriptions of Fig. 2).