

# Yields, Insecticide Productivity, and Bt Corn: Evidence from Damage Abatement Models in the Philippines

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This article provides evidence on the effects of Bt corn on yield and insecticide productivity in the Philippines using a damage abatement framework that accounts for selection and endogeneity issues. We find that the yield-enhancing effect (or the damage-abating effect) of Bt corn is more strongly observed under poor weather conditions as compared to the effect in more "normal" weather. The value of using insecticides for controlling pests is significantly reduced when farmers already use Bt technology as a means of control.

**Key words:** Bt corn, damage abatement, genetically modified crops, pesticide use, technology adoption, Philippines.

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## Introduction

Subsequent to the food price crisis in 2008, the need for affordable and available food and feed worldwide has increasingly become a pressing global concern. Both developed and developing countries acknowledge the need to enhance agricultural productivity to increase food and feed supply and consequently lower food prices. The issue of food security is now at the forefront of various global and domestic policy initiatives, and the role of biotech crops in these initiatives has never been more pronounced than it is today.<sup>1</sup> In November 2009, for example, China approved the commercial cultivation of *Bacillus Thuringiensis* (Bt) rice and phytase maize in an effort to raise domestic production of these food and feed crops (James, 2010).

Interestingly, Asia—where over half of the world's poor reside—has been slow in the uptake of GM crops that are grown specifically for food and feed. The only GM crop in Asia (and most other developing countries) that has a considerable planted area is Bt cotton, which is grown significantly in India (7.6 million ha) and China (3.8 million ha). Concerns related to environmental risk and consumer safety are likely factors that drive the region's ambivalence to biotech food and feed crop adoption (Azadi & Ho, 2010; Bayer, Norton, & Falck-Zepeda, 2010; Gaskell, 2000; Gouse, Pray, Kirsten, & Schimmelpfennig, 2005). For example, what could have been the first GM vegetable food crop to be released in a developing country was held back when the Indian government put a moratorium on the release of Bt eggplant on February 9, 2010. The only country in Asia that has approved and has been cultivating a GM food and feed

crop for a number of years is the Philippines, where Bt corn was first commercially deployed in 2002 (James, 2010).

Currently, 15 countries cultivate GM corn, of which more than 70% is in developed countries (United States, Canada, Spain, Czech Republic, Portugal, Romania, Poland, Egypt, and Slovakia) and the remainder in developing countries (Brazil, Argentina, South Africa, Uruguay, Philippines, Chile, and Honduras; GMO Compass, n.d.; James, 2010). In 2009, 30 of the 42 million hectares allocated to GM corn worldwide were in the United States (GMO Compass, n.d.).

Because the majority of the empirical evidence that pertain to GM corn has been done in developed countries, particularly the United States, Canada, and Spain (Carpenter & Gianessi, 2002; Demont & Tollens, 2004; Fernandez-Cornejo & Li, 2005; Marra, Pardey, & Alston, 2002; Sankula & Blumenthal, 2004, 2006), there is still a need to provide more evidence on the experience of farmers with Bt corn in developing country environments (Byerlee & Fischer, 2002; Lele, 2003; Qaim, 2005; Traxler, 2004). Farmers in developing countries are small-scale, more financially constrained, and likely to face shortfalls in input supplies as compared to their developed-country counterparts. Most of the existing literature on the effects of GM corn within a developing country context has been for South Africa and Argentina (Gouse et al., 2005; Gouse, Piesse, & Thirtle, 2006; Gouse, Pray, Schimmelpfennig, & Kirsten, 2006; Trigo & Cap, 2006). Even though there have been studies that examined the effect of Bt corn technology on yields and pesticide use in the Philippines (Cabanilla, 2004; Gonsalves, 2005; Yorobe & Quicoy, 2006), none of these existing studies have used a damage abatement specification to examine the impact of Bt corn on yields and pesticide productivity.

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1. *Biotech crops refer to genetically-modified (GM), insect-resistant (IR), herbicide-tolerant (HT), and Bacillus Thuringiensis (Bt) crops.*

The objective of this paper is to provide further evidence about the effects of Bt corn on yield and insecticide productivity and use in the Philippines by using a damage abatement framework that account for selection and endogeneity issues. The literature on the relationship between insecticide use, yields and GM corn adoption in the Philippines is based on simple partial budgets and standard production functions not specified within a damage abatement framework (Gonsalves, 2005; Yorobe & Quicoy, 2006). In couching the analysis within a damage abatement framework and using a richer set of surveys for 2003/2004 and 2007/2008, the question about Bt corn's effects on yields and insecticide productivity and use in the Philippines can be more precisely assessed.

### **Background: Corn Production and Bt Technology in the Philippines**

Corn is the second most important crop in the Philippines after rice, with approximately one-third of Filipino farmers (~1.8 million) depending on corn as their major source of livelihood. Yellow corn, which accounts for about 60% of total corn production (white corn accounts for the rest), is the corn type that is considered in this study. Most of the yellow corn produced in the Philippines is sold to the livestock and poultry feed mill industries, although some small farmers keep some proportion of output to be consumed as food, especially in times of poor harvest (Gerpacio, Labios, Labios, & Diangkinay, 2004).

Corn in the Philippines is typically grown rainfed in lowland, upland, and rolling-to-hilly agro-ecological zones of the country. There are two cropping seasons per year: wet season cropping (usually from March/April to August) and dry season cropping (from November to February). Most corn farmers in the Philippines are small, semi-subsistence farmers with the average farm size ranging from less than a hectare to about 4 hectares (Gerpacio et al., 2004; Mendoza & Rosegrant, 1995). Corn-producing households are also typically headed by men, though it is becoming increasingly common to see both husband and wife equally making farm decisions. These corn-producing households usually grow other cash crops in a small percentage of their cultivated area and some engage in small-scale (backyard) poultry and livestock production to augment income and supply home needs (Gerpacio et al., 2004; Mendoza & Rosegrant, 1995).

Land preparation for corn cultivation in the Philippines usually consists of one or two plowing operations,

harrowing to level the field and reduce the size of soil clods, and furrowing. These land preparation activities are often done with the use of water buffalos but can be mechanized on level terrain, especially if sufficient capital is available to pay for tractor rental. Furrowing is immediately followed by sowing and basal fertilizer application. Producers in major yellow corn producing areas historically plant the higher-yielding hybrid varieties as opposed to the local, traditional open pollinated variety (OPV), though there are some farmers in these areas who still plant OPVs primarily for home consumption. Chemical fertilizers are generally applied 25 to 30 days after planting. Off-barring, hilling-up, and manual or hand weeding are the common cultural practices to control weeds. In some cases, herbicides are used.

Harvesting, dehusking, and sometimes shelling are done manually with both family and hired labor. Corn is sun-dried immediately after harvest, usually on drying pavements at home or in common areas in the community. Dried ears to be sold to the feed industry are then typically shelled using mechanical shellers contracted through cooperatives or individual entrepreneurs in the area (some still manually shell the ears). Dried and shelled corn is immediately sold, making storage unimportant. Farmers usually sell their corn products directly in public markets or to feed millers, where prices are often higher. Corn farmers with loans from trader-financiers oftentimes have to sell their grain to these same trader-financiers even at lower prices. These trader-financiers loan out agricultural inputs (i.e., fertilizers, insecticides) to farmers at higher than market value, and deduct the value of agricultural inputs (plus interest) from the harvest sold back to them. Farmers who lack sufficient capital to fund their farm operations usually borrow from these trader-financiers since it is more convenient (i.e., no collateral required, easily accessible) than formal credit channels such as cooperatives and commercial rural banks (Gerpacio et al., 2004; Mendoza & Rosegrant, 1995).

The most destructive pest in the major corn-producing regions in the Philippines is the Asian corn borer (*Ostrinia furnacalis Guenee*; Morallo-Rejesus & Punzalan, 2002). Over the past decade or so, corn-borer infestation occurred yearly (i.e., infestation is observed in at least one region yearly), with pest pressure being either constant or increasing over time. Farmers report that yield losses from this pest range from 20% to 80%. Although the Asian corn borer is a major pest in the country, insecticide application has been moderate compared to other countries in Asia (i.e., China; Gerpacio et

al., 2004). Gerpacio et al. (2004) also report that corn farmers in major production regions only apply insecticides when infestation is high, and sometimes loan arrangements with trader-financiers impose constraints on the availability of insecticides when it is really needed (i.e., priority given to paying customers).

With the Asian corn borer as a major insect pest for corn in the country, the agricultural sector was arguably interested in Bt corn technology as a means of control. In addition, this technology was seen as having the potential to improve corn productivity in the country since yields have been low (~2 metric tons/ha) and corn imports have increased over time. Bt corn was first introduced in the Philippines in 1996 on a limited trial basis. Greenhouse evaluations were done in local and international plant-breeding laboratories based in the country, in collaboration with Monsanto Philippines, Inc. Between 1999 and 2002, after approval from the National Committee on Biosafety in the Philippines (NCBP), field trials of Bt corn were conducted in the major corn-producing areas of the country. Finally, in December 2002, the Philippine Department of Agriculture provided regulations for the commercial use of GM crops and approved the commercial distribution of Bt corn (specifically Monsanto's Yieldgard™ 818 and 838).

In the first year of its commercial adoption, 2003, Bt corn (including that combined with herbicide tolerance) were grown in only 1% of the total area planted with corn—on about 10,769 hectares. In 2007, about 16.4% of corn planted was Bt, and in 2009 this increased to 21.9%, which is about 280,417 hectares (Philippine Department of Agriculture Biotech Core Team, personal communication, May 2010). Apart from Monsanto, Pioneer Hi-Bred (since 2003) and Syngenta (since 2005) currently sell Bt corn seeds in the Philippines. In addition to hybrid seeds, these companies have extensive operations in the marketing of agricultural chemicals in the country (Cabanilla, 2007).

## Data Description

The data used in this study come from two sources: (1) the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) corn survey for crop year 2003/2004 and (2) the International Food Policy Research Institute (IFPRI) corn survey for crop year 2007/2008. These comprehensive, farm-level surveys were carried out during the wet and dry seasons where information on corn farming systems and environment, input and output relations, costs and revenues, marketing environment, and other factors related to Bt corn

cultivation were collected. Detailed data on quantities and prices of corn outputs (e.g., production, domestic prices received in Philippine peso [PhP]), purchased inputs (e.g., fertilizer, insecticides, hired labor) and non-purchased inputs (e.g., unpaid family labor, depreciation) were gathered, as well as information on household characteristics and subjective questions on Bt technology (i.e., their perception of the risks of Bt). Actual data collection was implemented through face-to-face interviews.

The 2003/2004 ISAAA survey included four major yellow corn growing provinces: Isabela, Camarines Sur, Bukidnon, and South Cotabato. To arrive at the sample of Bt respondents to be surveyed, three towns and three barangays (smallest political unit in the Philippines) within each town were initially chosen in each of the four provinces based on the density of Bt corn adopters in the area. Using a list of Bt corn farmers from local sources (i.e., local Monsanto office), simple random sampling was used to determine Bt corn respondents within selected barangays. The exceptions are Camarines Sur and Bukidnon where all Bt respondents were included due to the small number of Bt corn farmers in the selected barangays within these two provinces. The non-Bt sample was then selected by randomly sampling from a list of non-Bt farmers in the proximity of the selected Bt farmers (i.e., typically within the same barangay) to minimize agro-climatic differences between the subsamples. In addition, to facilitate comparability, physical and socio-economic factors were compared to assure that adopters and non-adopters were similar. The factors used for comparison include yield, area, farming environment, input use, insecticide use, costs and returns, reasons for adoption, knowledge about Bt corn, information sources, and perceptions on planting Bt corn.<sup>2</sup> In the end, based on the data collected from 470 respondents, only 407 observations (101 Bt adopters and 306 non-Bt adopters) were used in the analysis due to incomplete information and missing data issues.

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2. *The stratified random sampling procedure for non-Bt respondents was designed to reduce potential selection problems. This sampling approach reduces placement bias that is related to the promotion programs of seed companies only in certain locations. Also, placement bias is not a critical issue given that seed companies' promotion efforts were uniformly performed in the major corn growing provinces included in the survey (based on our consultation with Philippine social scientists working in those areas).*

**Table 1. Sample means: Full sample, Bt corn adopters, and non-Bt corn adopters, 2003/2004 and 2007/2008.**

| Variable                     | 2003/2004                  |                            |                                | 2007/2008                  |                            |                                |
|------------------------------|----------------------------|----------------------------|--------------------------------|----------------------------|----------------------------|--------------------------------|
|                              | Full sample<br>(407 farms) | Bt adopters<br>(101 farms) | Non-Bt adopters<br>(306 farms) | Full sample<br>(468 farms) | Bt adopters<br>(254 farms) | Non-Bt adopters<br>(214 farms) |
| Seeds (kg/ha)                | 18.6                       | 19.1                       | 18.4                           | 18.8                       | 18.3                       | 19.4                           |
| Seed price (PhP/kg)          | 143.3                      | 224.8                      | 116.3                          | 248.8                      | 310.1                      | 176.1                          |
| Labor (man-days/ha)          | 56.0                       | 54.2                       | 56.6                           | 51.9                       | 53.9                       | 49.5                           |
| Fertilizer (kg/ha)           | 413.4                      | 452                        | 400.6                          | 437.5                      | 475.1                      | 392.8                          |
| Herbicides applied (L/ha)    | 0.3                        | 0.4                        | 0.3                            | 1.4                        | 1.8                        | 1.0                            |
| Insecticides applied (kg/ha) | 0.6                        | 0.3                        | 0.8                            | 0.6                        | 0.2                        | 1.0                            |
| Insecticide price (PhP/kg)   | 240.9                      | 188.7                      | 258.2                          | 321.1                      | 197.4                      | 467.9                          |
| Yield (kg/ha)                | 3912.9                     | 4849.5                     | 3603.8                         | 4249.5                     | 4681.9                     | 3731.3                         |
| Corn area (ha)               | 2.0                        | 2.4                        | 1.9                            | 1.3                        | 1.3                        | 1.3                            |
| Corn price (PhP/kg)          | 8.0                        | 8.8                        | 7.7                            | 10.1                       | 10.3                       | 9.9                            |
| Pest pressure <sup>a</sup>   | --                         | --                         | --                             | 0.38                       | 0.36                       | 0.41                           |

<sup>a</sup> The pest pressure variable in this study comes from a question where farmers were asked about the pest pressure in the current year relative to last year (i.e., whether it is less severe, same, more severe, or they do not know). A binary "pest pressure" variable is then created where it is equal to one when the farmer's response is less severe and zero otherwise.

The 2007/2008 IFPRI survey were conducted in a similar manner as the 2003/2004 ISAAA survey but was confined to the provinces of Isabela and South Cotabato. Due to the small number of Bt respondents in the provinces of Camarines Sur and Bukidnon in the ISAAA 2003/2004 survey, it was deemed more cost-efficient to exclude them in the 2007/2008 IFPRI survey but include more observations in Isabela and Cotabato where the bulk of Bt adopters reside. Seventeen top corn-producing villages were then selected from these two provinces. These villages are primarily agricultural with yellow corn as the primary crop followed by rice paddy, coconut, and some fruit crops. A total of 468 randomly-selected households were interviewed in the 17 villages (254 were Bt corn adopters and 214 were non-Bt adopters). The 468 households were allocated among the 17 villages with a fixed sampling fraction. The farmers interviewed were randomly chosen from lists of all yellow corn growers in each village. Lists were provided by the village heads. Note that the 2007/2008 data included additional information about the perceived level of pest pressure at the time the respondents cultivated corn and the distance of seed suppliers from their farms (i.e., this information is not available in the 2003/2004 survey).

Although the 2007/2008 IFPRI survey does not track the same households surveyed in the 2003/2004 ISAAA survey (i.e., not a panel data set), it is nonetheless instructive to use data from both survey years to analyze how the impacts of Bt corn have changed over time in the Philippines. Recall that the 2003/2004 crop

year is the first year that Bt corn became available to Philippine farmers. Hence, data from this crop year gives information about the "initial" impacts of Bt corn, as the 2007/2008 crop year provides impact estimates after several years of the technology being available.

Table 1 presents summary statistics of the pertinent input and output variables (delineated by crop year and Bt adoption status). The data reported here refers to the input/output data for the main corn plot of the farmer where he/she only plants either Bt corn or non-Bt corn.<sup>3</sup> In both years, Bt farmers applied more fertilizer and herbicides, but less insecticides, compared to their conventional counterparts. At the same time, Bt farmers faced higher seed and corn output prices, as well as experienced higher yields. Regardless of survey year, conventional farmers paid more for insecticides. There is considerable price variation in insecticide prices because of quality, or active ingredient disparities; conventional farmers might be using insecticides with higher levels of toxicity, or the active ingredient. In 2003/2004, Bt adopters used more seed input than conventional farmers, while the opposite occurred in 2007/2008.

3. There is no diversification within the plot-level unit of analysis where the plot is planted with both Bt and non-Bt corn (i.e., the farms that are classified as Bt report data specifically for their Bt plot).

## Empirical Framework

### **The Cobb-Douglas Production Function: Testing for Endogeneity and Selection**

Before investigating the effect of Bt on yields and pesticide productivity using a damage abatement specification, we find it useful (for comparative purposes) to first estimate a production function with a conventional Cobb-Douglas specification. In addition, estimating the Cobb-Douglas specification allows one to more easily test and assess whether there are selection or endogeneity issues associated with the insecticide use and Bt adoption variables. These tests are more straightforward to implement within a linearized Cobb-Douglas specification (i.e., log-log specification) rather than with a non-linear damage abatement specification. Therefore, though the maintained assumption is that the Cobb-Douglas production function does not properly model the damage-abating nature of insecticides, herbicides, and Bt, this model is nevertheless considered useful in providing a simple approach to carry out selection and endogeneity tests.

In a typical Cobb-Douglas production function for crops, yield,  $Y$ , is modeled as a function of a vector of inputs,  $\mathbf{Z}$ . Thus, yield is given by

$$Y=F(\mathbf{Z})=\alpha_0\prod_{i=1}^n Z_i^{\beta_i}, \quad (1)$$

where  $\mathbf{Z}$  includes inputs (such as quantity of seeds used, insecticides, herbicides, fertilizer applied, and labor), and  $\alpha_0$  and  $\beta_i$  are parameters to be estimated. A Bt dummy variable is typically included in  $\mathbf{Z}$  if there is interest in evaluating the impact of Bt technology. In instances where information on pest pressure is available, it is recommended that this information be included in  $\mathbf{Z}$  because studies have shown that insecticide productivity is underestimated when it is not in the production function specification (Norwood & Marra, 2003).<sup>4</sup>

As mentioned above, estimating the Cobb-Douglas production function in Equation 1 would likely give rise to two potential problems related to endogeneity and selection (Huang, Hu, Rozelle, Qiao, & Pray, 2002; Qaim & de Janvry, 2005; Shankar & Thirtle, 2005). The

first issue pertains to the endogeneity of the insecticide use decisions (Huang et al., 2002; Shankar & Thirtle, 2005). Because insecticides are typically applied in response to pest or production shocks (i.e., pest pressure that is typically unobserved to the analyst), then it is possible that the residuals of the production function are correlated with insecticide use. Hence, the insecticide use variable can be endogenous in this case and this would cause inconsistent parameter estimates.

One approach to dealing with this endogeneity issue is simply including a pest pressure variable that would eliminate the unobservability of pest shocks that can potentially cause the bias. As mentioned in Footnote 4, a self-reported pest pressure variable is available in the 2007/2008 data and this would help alleviate the endogeneity problem for that crop year.<sup>5</sup> When a pest pressure variable is not available (as in the 2003/2004 data), one approach is the instrumental variable (IV) estimation method. In this approach, valid instruments are needed that are correlated with insecticide use but uncorrelated with unobserved pest pressure. Consistent with Huang et al. (2002), we use insecticide price as our IV and regress this variable on insecticide use. The residual from this ordinary least squares (OLS) regression is then added to the production function in Equation 1 as an additional regressor. If the residual is statistically insignificant, then endogeneity is not severe and the actual insecticide use variable could still be used in an OLS regression of Equation 1. However, if the residual is statistically significant, then the predicted values of insecticide use would need to be used in the estimation of Equation 1 or the damage abatement equation below. This test for endogeneity is one variant of the so-called Hausman test and this test was applied for the 2003/2004 data, as well as the 2007/2008 data (even though a pest pressure variable is available in that latter survey year).

The second issue with straightforward OLS estimation of Equation 1 that includes a Bt dummy variable is whether farmers systematically self-select themselves into either Bt or non-Bt corn category based on certain farm or farmer characteristics, which then causes a selectivity (or selection) problem (Shankar & Thirtle, 2005). It is plausible that Bt adopters are farmers with

4. Information on pest pressure was available only for the 2007/2008 survey and as such this variable was not included in the conventional Cobb-Douglas production function estimation using data from 2003/2004.

5. The pest pressure variable in this study comes from a question where farmers were asked about the pest pressure in the current year relative to last year (i.e., whether it is less severe, same, more severe, or they do not know). Then, we created a binary pest pressure variable where it is equal to one when the farmer's response is less severe and zero otherwise.

better-unobserved farm management ability (relative to the non-adopters). This differential in farm management ability can then be what drives the observed yield disparities between adopters and non-adopters, not the effect of the Bt variety on yields. Hence, estimating Equation 1 without controlling for selection issues might lead to inconsistent parameter estimates and incorrect yield impact estimates between the subsamples.

In this study, we address the selection issue by using the Heckman selectivity model. Shankar and Thirtle (2005) also used this approach in their study of Bt cotton in South Africa. In the first stage of the Heckman approach, a regression for the Bt adoption decision is modeled using a probit model from which the inverse Mills' ratio (IMR) is generated.<sup>6</sup> To be consistent with the IV approach to testing endogeneity above, we use the seed price as the independent variable in the first-stage probit model for 2003/2004. This also allows us to identify the probit model (i.e., that has an independent variable that affects the decision to adopt Bt but does not directly affect the yield outcomes) for proper inferences. For 2007/2008, we include distance to seed supplier as an additional independent variable in the probit equation. After estimating the first-stage probit, the IMR is then appended as an additional variable in separate estimations of Equation 1 for adopters and non-adopters where statistical significance (in either equation) confirms the presence of selection bias. In this case, the use of predicted values for Bt adoption, instead of the actual Bt dummy, is preferred when estimating a production function with a Bt dummy variable in the right-hand side of the equation.

### The Damage Abatement Framework

Modeling the effect of agricultural inputs on crop is not straightforward as Equation 1 suggests. The manner in which certain inputs such as insecticides and herbicides enter the production function has led people to question the conventional Cobb-Douglas specification. Lichtenberg and Zilberman (1986) were the first to propose a control model for insecticides that distinguishes insecticides as damage-abating rather than as a yield-increasing input. In previous studies, inputs are presumed to directly increase potential yields as in Equation 1. In the damage abatement framework, on the other hand, inputs do not directly increase the potential yield but rather

reduce the damage to potential yields. As such, the standard  $Y = F(\mathbf{Z})$  in Equation 1 is augmented to include a multiplicative factor,  $G(\mathbf{X})$ , that runs over the interval (0,1) that represents the fraction of potential yields that remain after accounting for crop loss or damage. Crop loss is a function of damage-abating inputs,  $\mathbf{X}$ , so that  $F(\mathbf{Z})$  is the potential maximum yield with zero pest damage (alternatively this is maximum abatement due to the employment of the damage-abating inputs,  $\mathbf{X}$ ). Hence, the more effective the damage-abating inputs are, the less crop damaged, and the fraction tends to 1. The effective yield,  $Y$ , is then modeled as

$$Y = F(\mathbf{Z})G(\mathbf{X}) \quad (2)$$

under the damage abatement framework where the vector  $\mathbf{Z}$  consists of conventional, directly yield-enhancing inputs such as labor, seeds, among others, and the vector  $\mathbf{X}$  are damage-abating inputs such as insecticides, herbicides, and insect-resistant technologies such as Bt.

Previous literature do not offer definitive guidance as to the proper functional form of the damage abatement function,  $G(\mathbf{X})$  though several cumulative distribution functions are available, such as the logistic, Weibull, and exponential, among others (Sexton, Lei, & Zilberman, 2007). However, the logistic specification has been used in most empirical work relating to Bt technology (Qaim & de Janvry, 2005; Shankar & Thirtle, 2005). Also, several studies have shown that the logistic specification generally represents the pest abatement relationship reasonably well and tends to be more flexible (Lichtenberg & Zilberman, 1986; Qaim & Zilberman, 2003; Shankar & Thirtle, 2005). As such, the logistic specification of the damage control function,  $G(\mathbf{X})$ , is used in this study.<sup>7</sup> On the other hand, the conventional Cobb-Douglas specification is used for the  $F(\mathbf{Z})$  function for the yield-enhancing inputs. Therefore, the resulting damage abatement specification of the production function (that includes a Bt dummy) can be expressed as follows:

$$Y = \alpha_0 \prod_{i=1}^n Z_i^{\beta_i} \left[ 1 + \exp \left( \mu - \sum_{j=1}^k \sigma_j X_j - \lambda Bt \right) \right]^{-1}, \quad (3)$$

6. The inverse Mills' ratio is the ratio of the probability density function over the cumulative distribution function.

7. Although not reported here in the interest of space, we also estimated a specification that uses an exponential function and found that majority of the results from this specification is the same as in the logistic specification. The results from this exponential specification are available from the authors upon request.

**Table 2. Cobb-Douglas estimates, insecticide endogeneity test, and Bt selection test: 2003/2004.**

| Variable    | Cobb-Douglas |         | Insecticide endogeneity test |         | Bt selection test: Adopters |         | Bt selection test: Non-adopters |         |
|-------------|--------------|---------|------------------------------|---------|-----------------------------|---------|---------------------------------|---------|
|             | Coeff.       | p-value | Coeff.                       | p-value | Coeff.                      | p-value | Coeff.                          | p-value |
| Intercept   | 7.02         | <0.01   | 7.03                         | <0.01   | 7.35                        | <0.01   | 7.11                            | <0.01   |
| Seed        | 0.37         | <0.01   | 0.36                         | <0.01   | 0.40                        | 0.13    | 0.24                            | 0.03    |
| Fertilizer  | 0.07         | <0.01   | 0.07                         | <0.01   | 0.13                        | 0.25    | 0.06                            | 0.01    |
| Labor       | -0.08        | 0.12    | -0.07                        | 0.13    | -0.21                       | 0.03    | <0.01                           | 0.97    |
| Insecticide | 0.01         | 0.25    | 0.01                         | 0.17    | 0.01                        | 0.38    | 0.01                            | 0.08    |
| Herbicide   | <0.01        | 0.83    | <0.01                        | 0.83    | <-0.01                      | 0.84    | <-0.001                         | 0.68    |
| Residual    | --           | --      | -0.01                        | 0.44    | --                          | --      | --                              | --      |
| IMR         | --           | --      | --                           | --      | -0.07                       | 0.46    | -0.34                           | <0.01   |

**Table 3. Cobb-Douglas estimates, insecticide endogeneity test, and Bt selection test: 2007/2008.**

| Variable      | Cobb-Douglas |         | Insecticide endogeneity test |         | Bt selection test: Adopters |         | Bt selection test: Non-adopters |         |
|---------------|--------------|---------|------------------------------|---------|-----------------------------|---------|---------------------------------|---------|
|               | Coeff.       | p-value | Coeff.                       | p-value | Coeff.                      | p-value | Coeff.                          | p-value |
| Intercept     | 5.19         | <0.01   | 5.19                         | <0.01   | 6.72                        | <0.01   | 3.95                            | <0.01   |
| Seed          | -0.10        | 0.29    | -0.11                        | 0.30    | -0.19                       | 0.18    | 0.11                            | 0.48    |
| Fertilizer    | 0.41         | <0.01   | 0.41                         | <0.01   | 0.18                        | 0.01    | 0.56                            | <0.01   |
| Labor         | 0.22         | <0.01   | 0.22                         | <0.01   | 0.28                        | <0.01   | 0.13                            | 0.06    |
| Insecticide   | -0.02        | 0.01    | -0.01                        | 0.04    | -0.01                       | 0.51    | <-0.01                          | 0.92    |
| Herbicide     | <-0.01       | 0.80    | <-0.01                       | 0.86    | -0.02                       | 0.03    | <0.01                           | 0.55    |
| Pest pressure | -0.01        | 0.74    | -0.01                        | 0.74    | -0.07                       | 0.21    | 0.07                            | 0.28    |
| Residual      | --           | --      | -0.01                        | 0.37    | --                          | --      | --                              | --      |
| IMR           | --           | --      | --                           | --      | -0.13                       | 0.06    | 0.06                            | 0.34    |

where  $\mu$ ,  $\sigma_j$ , and  $\lambda$  are parameters to be estimated; Bt is a dummy variable (=1 if the farmer adopts Bt corn, =0 otherwise); and the remaining variables are as described in Equations 1 and 2.

### Estimation and Results

#### ***Cobb-Douglas Production Function, Endogeneity, and Selection***

The estimated coefficients for the Cobb-Douglas production function are presented in Tables 2 and 3 for crop years 2003 and 2007, respectively (see Columns 2 and 3 of the respective Tables). The signs of the statistically significant variables follow a priori expectations except for insecticides in 2007. This unexpected result might have been caused by not properly treating the insecticide variable as a damage control input.

The Hausman test reveals that insecticide endogeneity might not be severe enough in the context of our data sets to cause significant bias in our results (see Columns 4 and 5 in Tables 2 and 3). The appended residual from a

first stage IV estimation of insecticide use as a function of insecticide price (Appendix Table 1) is not statistically significant in both the 2003/2004 and 2007/2008 crop years. This suggests that the null hypothesis of no correlation between insecticide use and the error term cannot be rejected. Shankar and Thirtle (2005) also had a similar result for smallholder cotton producers in South Africa. Hence, actual insecticide application (rather than the predicted) is used in the proceeding analysis with the damage abatement specification.

The Bt selection tests for adopters and non-adopters, on the other hand, indicate that selection bias might indeed be a problem in our data sets (see Columns 7-9 in Tables 2 and 3). The IMR is statistically significant for non-adopters in 2003 and adopters in 2007, which suggests the presence of selection issues. Hence, the predicted value of the Bt adoption variable ( $Bt^{pred}$ ), rather than the actual Bt dummy variable, is used in the proceeding analysis with the damage abatement specification.

**Table 4. Damage abatement model estimates under logistic specification: 2003/04 and 2007/08.**

| Variable                         | Crop year 2003/2004 |         | Crop year 2007/2008 |         |
|----------------------------------|---------------------|---------|---------------------|---------|
|                                  | Coeff.              | p-value | Coeff.              | p-value |
| <b>F(Z): Conventional</b>        |                     |         |                     |         |
| Intercept                        | 7.21                | <0.01   | 6.44                | <0.01   |
| Seed                             | 0.26                | <0.01   | -0.03               | 0.69    |
| Fertilizer                       | 0.14                | <0.01   | 0.24                | <0.01   |
| Labor                            | -0.08               | 0.06    | 0.16                | <0.01   |
| Pest pressure                    | --                  | --      | -0.04               | 0.29    |
| <b>G(X): Damage abatement</b>    |                     |         |                     |         |
| Intercept                        | -0.92               | 0.02    | -0.55               | 0.13    |
| Insecticide ( $\sigma_1$ )       | 0.07                | 0.33    | 0.01                | 0.91    |
| Herbicide ( $\sigma_2$ )         | 0.01                | 0.88    | 0.17                | 0.32    |
| Bt <sup>pred</sup> ( $\lambda$ ) | 2.33                | 0.32    | 11.10               | 0.04    |
| R <sup>2</sup>                   | 0.89                |         | 0.89                |         |
| AIC                              | 7052.26             |         | 8001.98             |         |
| BIC                              | 7084.31             |         | 8039.09             |         |

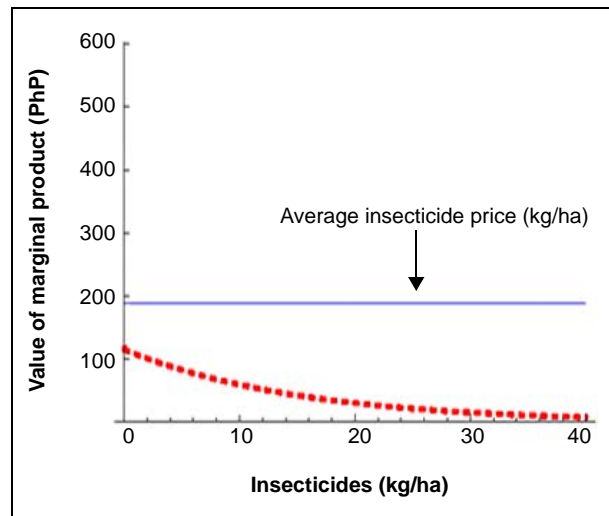
**Results from the Damage Abatement Specification**

Parameter estimates from the damage abatement specification are presented in Table 4. For the conventional inputs, all statistically significant variables (at the 1% level) follow *a priori* expectations. However, the damage-abating insecticide and herbicide inputs are not statistically significant in both crop years. As mentioned in the background section above, insecticide use in the Philippines is moderate relative to other countries and the low absolute average levels of insecticide use suggest that additional applications might not result in statistically significant damage abatement. It is also possible that corn borer in the country have developed some resistance to available insecticides (given the yield losses from these pests range from 20% to 80%; Pingali & Gerpacio, 1998).

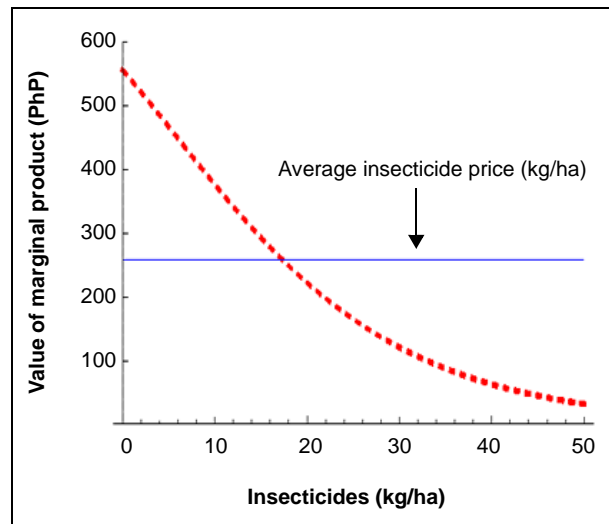
Examining the value of marginal product (VMP) associated with increased use of insecticides can help provide more information with respect to the productivity of insecticide use in the presence or absence of Bt technology. The VMP of insecticides for the logistic damage abatement function in Equation 3 is as follows:

$$VMP(Insecticide) = P \cdot F(Z)$$

$$\cdot \frac{\sigma_1 \cdot \exp(\mu - \sigma_1 Insecticide - \sigma_2 Herbicide - \lambda Bt^{pred})}{[1 + \exp(\mu - \sigma_1 Insecticide - \sigma_2 Herbicide - \lambda Bt^{pred})]^{-2}} \quad (4)$$



**Figure 1. VMP plot for Bt (using Bt sample means), 2003/2004.**



**Figure 2. VMP plot for non-Bt (using non-Bt sample means), 2003/2004.**

In 2003, Bt farmers in our data set paid PhP 188.7 for a kilogram of insecticide (Table 1), though the VMP of insecticide (calculated at the means of inputs) is lower at PhP 113.1 (Figure 1). Hence, it would have been optimal for farmers not to apply any amount of insecticides when planting the Bt variety (i.e., no intersection between the price and VMP curve). Non-Bt farmers, on the other hand, would have been better off if they applied an additional 17 kg/ha of insecticide relative to the 0.8 kg/ha they applied because the VMP of insecticide use is PhP 542.75 and the average price paid for an additional kg/ha was PhP 258.2 (Figure 2).



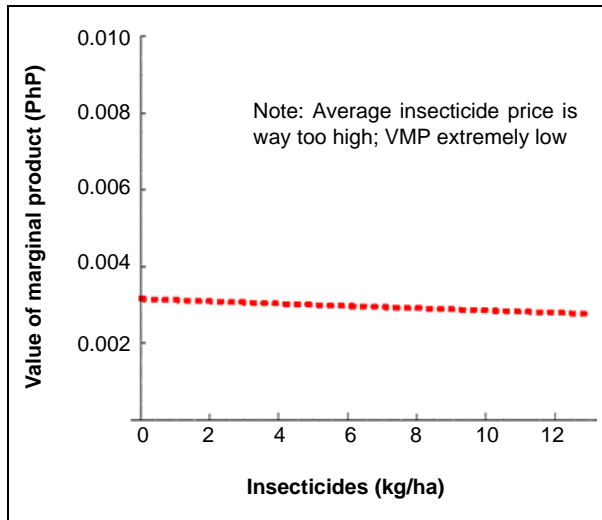


Figure 3. VMP plot for Bt (using Bt sample means), 2007/2008.

In 2007, applying any amount of insecticide seems to have been suboptimal for both Bt adopters and non-adopters. In Figure 3, the VMP associated with increased insecticide use was very low and close to zero at PhP 0.003 on Bt plots while the average price paid by farmers for insecticide is PhP 197.4 per kg (Table 1). Similarly, Figure 4 suggests that on non-Bt plots, the VMP of insecticide was way less at PhP 97.1 than the price farmers paid, on average (PhP 467.9). Nonetheless, it should be noted that Bt adoption considerably reduces the VMP of insecticides in both survey years, which is consistent with the notion that the value of insecticide use is lower when the corn borer Bt seed technology is utilized.

The parameter estimates for Bt in Table 4 also provide interesting information regarding the damage-abating nature of this technology. Notice that Bt has a statistically significant effect on damage abatement in 2007 but not in 2003. Though this result might be surprising at first glance (i.e., we expected Bt to be statistically significant in both years), this result is not entirely unfamiliar. Using a two-year panel of smallholder farmers who adopted Bt cotton in Makhathini Flats in Kwa-zulu-Natal, Thirtle, Beyers, Ismael, and Piesse (2003) found that in the first year, when the weather was good for cotton, Bt did not result in higher yields nor gross margins. However, in the following year when the weather was bad (with an unusually heavy rainfall), Bt adopters suffered lower yield reductions. They argue that this supports Monsanto’s claim that as rains wash off the insecticides that necessitate reapplication, Bt cotton buffers the effect of weather on bollworm control.

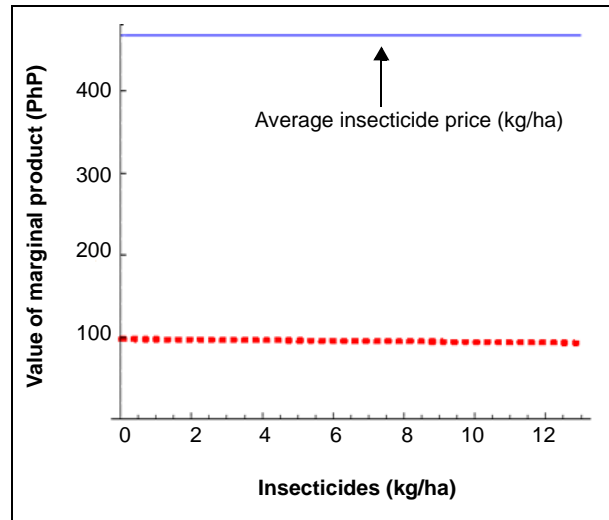


Figure 4. VMP plot for non-Bt (using non-Bt sample means), 2007/2008.

As in Thirtle et al. (2003), but using a different survey structure, we found 2003 was a good year for farmers in the Philippines to grow corn, though 2007 was a year of bad weather in the major corn-producing areas (i.e., extreme dry spell in Isabela province and unusually heavy rains in South Cotabato province; Yumul, Jr., Cruz, Dimalanta, Servando, & Hilario, 2010). In our case, the absence of rain did not allow for the immediate effectiveness of insecticides in 2003 and the heavy rainfall in 2007 did not allow for retention of the insecticides where they were sprayed. In a bad weather event, Bt corn overcomes these limitations in controlling for corn borers with insecticides and the effectiveness of this technology is more strongly felt (as in the 2007 case in our data set). Hence, in 2007, Bt had a statistically significant abating effect on corn yield losses, though no significant effect is observed in 2003. This result is consistent with earlier evidence where farmers who use small doses of insecticides in their crop in spite of high pest pressure realize significant yield effects with the use of the Bt variety (Qaim & de Janvry, 2005; Qaim & Zilberman, 2003). These results are important because it gives more insights about the circumstances where Bt technology would be advantageous over traditional insecticide application as a means of pest control.

To gain some more perspective on the “yield effect” of Bt adoption, we computed the difference between the predicted yields (at the means) for Bt adopters and non-adopters and tested its significance. Bt farmers harvested more per hectare than non-Bt farmers by as much as 1,194.2 kg/ha (33%) and 1,483.3 kg/ha (45%) in 2003 and 2007, respectively (i.e., these differences are

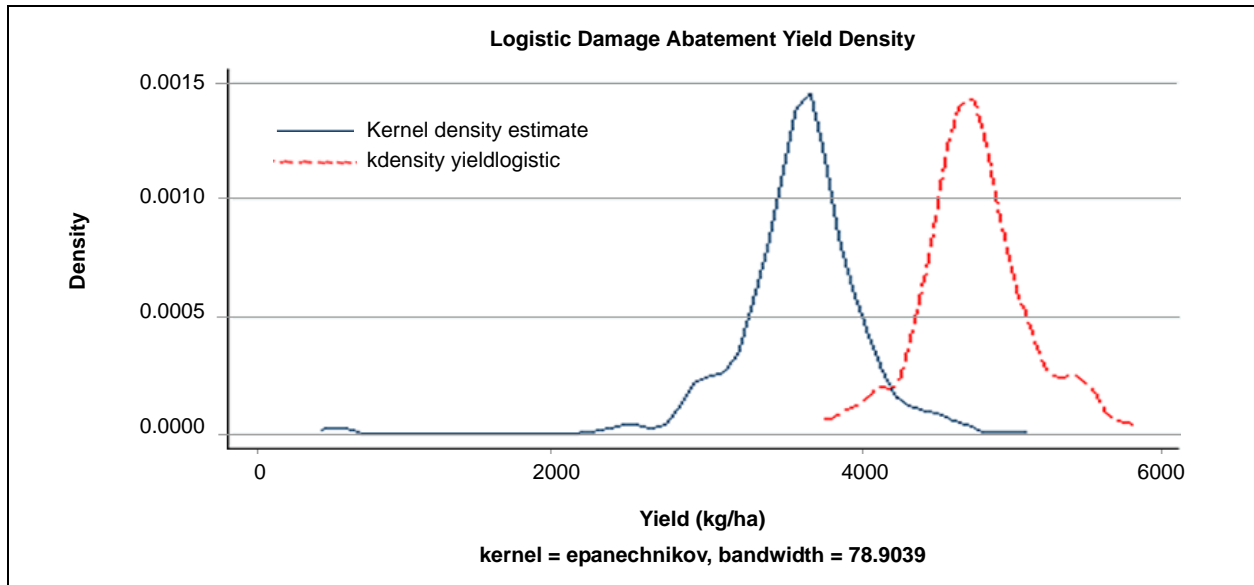


Figure 5. Comparison of yield densities between Bt (dashed) and non-Bt adopters, 2003/04.

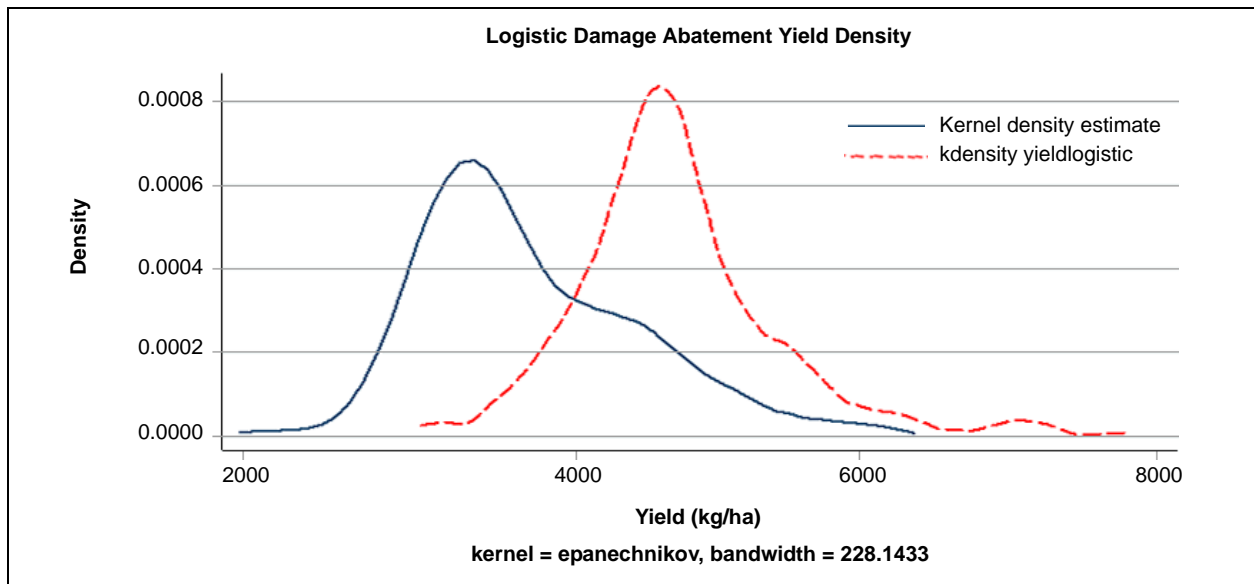


Figure 6. Comparison of yield densities between Bt (dashed) and non-Bt adopters, 2007/08.

statistically significant at the 1% level). This observed, a statistically significant yield-increasing effect of Bt is consistent with previous Bt corn studies in the Philippines that used partial budgets and more traditional production function estimations (for examples, see Cabanilla, 2004; Gonsalves, 2005; Yorobe & Quicoy, 2006). We also generated yield density graphs from the predicted values of the damage abatement specification in Figures 5 and 6, where the dashed lines refer to Bt adopters. Figures 5 and 6 show the shift in the yield dis-

tribution with Bt. Evidently, yield densities in 2007 are slightly skewed to the right, in contrast to the left skewed densities in 2003. This gives credence to our earlier claim that adverse weather in 2007 depressed corn yields relative to those in normal years such as 2003.

## Conclusions

The results of our study suggest that Bt corn in the Philippines provides statistically significant yield damage abatement, especially in poor weather conditions (i.e., 2007/2008). Yields of Bt corn producers tend to be statistically higher than non-Bt adopters in the two years considered in the study: one year with normal weather (2003/2004) and the other with poor weather (2007/2008). But the yield-increasing effect of Bt is more pronounced in the year with poor weather conditions. We posit that insecticide use is less effective in poor weather conditions (e.g., extremely wet weather washes insecticides away and reduces its effectiveness). Therefore, the yield-enhancing (or the damage-abating) effect of Bt is more strongly felt in this environment (i.e., the yield difference between Bt and non-Bt adopters is larger in poor weather).

The estimates from the damage abatement specification also suggest that the value of insecticide use is reduced when using Bt corn. This is consistent with the idea that applying insecticide is redundant when a technology that inherently controls for lepidopteran pests is already being used (i.e., Bt technology is effectively a substitute for insecticide use).

These results provide further information about the yield and insecticide use effects of Bt corn in a developing-country environment and also gives further insights on the circumstances in which Bt corn might have a significant yield impact. The ability to control insect damage under poor weather conditions implies that productivity of Philippine corn farmers can be enhanced when using Bt corn technology. Moreover, the variability of corn yields over time would also probably be lowered if Bt technology does indeed allow for better yields in bad weather. This information is valuable to policymakers in the Philippines given the recent emphasis on increasing the productivity of the local corn sector to enhance food security in the country. The Philippines has been a net importer of corn for some time and the potential yield effects of Bt corn found in this study might encourage policy makers to promote this technology as a means to reduce reliance on foreign corn.

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## Appendix

**Table A1. First-stage IV estimates: Insecticide=f(insecticide price).**

| Variable          | Crop year 2003/2004 |         | Crop year 2007/2008 |         |
|-------------------|---------------------|---------|---------------------|---------|
|                   | Coeff.              | p-value | Coeff.              | p-value |
| Intercept         | 0.4370              | <0.01   | 0.4057              | <0.01   |
| Insecticide price | 0.0008              | <0.01   | 0.0005              | <0.01   |
| R-squared         | 0.04                |         | 0.05                |         |
| No. of obs.       | 407                 |         | 468                 |         |

**Table A2. First-stage Probit estimates: Bt=f(seed price and/or distance to supplier).**

| Variable             | Crop year 2003/2004 |         | Crop year 2007/2008 |         |
|----------------------|---------------------|---------|---------------------|---------|
|                      | Coeff.              | p-value | Coeff.              | p-value |
| Intercept            | -7.022              | <0.01   | -5.008              | <0.01   |
| Seed price           | 0.040               | <0.01   | 0.021               | <0.01   |
| Distance to supplier | --                  | --      | 0.023               | 0.06    |
| Pseudo-R-squared     | 0.04                |         | 0.05                |         |
| No. of obs.          | 407                 |         | 458                 |         |