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Further evidence on pesticides, productivity and farmer health: Potato production in Ecuador

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1. Introduction

A recent paper by Antle and Pingali (1994) showed that farmers' health had a significant impact on the productivity of Philippine rice farms, and that pesticide use in rice production had a significant impact on farmers' health. A simulation analysis showed that restricting the use of insecticides that posed the greatest health risk was a 'win–win' policy, as it would increase both the health and productivity or Philippine rice farmers. Two features of Philippine rice production that could affect the outcome of that analysis are, first, the low productivity of insecticides in rice production, and second, the humid tropical rice paddy environment where farmers' use of protective clothing is minimal. The Antle and Pingali study left open the question of whether this 'win–win' result would hold in a situation where the marginal productivity of insecticides or other pesticides is higher, and where the climate is more compatible with the use of self-protective clothing or other equipment.

This study replicates and extends the Antle and Pingali study using data from a potato producing region of Ecuador. Potato production in Ecuador is vulnerable to two major pests, the soil-dwelling larvae of the Andean weevil (*Premnotrypes vorax*) and the late blight fungus (*Phytophthora infestans*). The use of insecticides and fungicides is considered by both farmers and agricultural scientists as important in the control of these pests, and as many as 12 applications of both insecticides and fungicides are used in their control. Potato production occurs in a temperate highland climate compatible with the use of protective clothing such as rubber boots and gloves. The Ecuador study also provides larger samples of production and health data, and these data allow the crop production technology and the health production function to be estimated jointly, increasing statistical reliability. In addition, in the Ecuador study, a measure of neurobehavioral function is used as an indicator of farmer health, an indicator that has been validated in the occupational health literature and that should be closely related to farmers' managerial and decision-making capacity. The Philippine

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study used an ad hoc index of health that has not been validated independently.

The findings of this Ecuadorian study are remarkably similar to those of the Philippine study, despite substantial differences in the types and amounts of pesticides that are used, in their productivity, and in the physical environment in which they are used. Analysis of the Ecuador data shows that health has a statistically significant effect on productivity, with an elasticity of cost with respect to health in the same range as in the Philippine study. Also, like the Philippine study, the Ecuador study shows that pesticide use has a significant effect on health. A simulation analysis similar to the one conducted in the Philippine rice study is used to explore the effects that reductions in pesticide use would have on health and productivity.

The results of this study show that despite the important role that insecticides play in controlling the Andean weevil insect pest, a reduction in the use of the principal insecticide used to control this pest, carbofuran, could raise productivity and also improve farmers' health. One important difference in the two studies does emerge, however. In the Philippine analysis, a policy reducing the use of all pesticides (herbicides and insecticides) was less efficient than a reduction in insecticides alone, but both policies would result in the win–win outcome. In the Ecuador case, where the productivity of pesticides is higher, however, the win–win outcome can be obtained only when the policy targets the insecticides that pose the greatest health risk. When the simulated policy reduces the use of all pesticides, both fungicides and insecticides, a tradeoff between health and productivity emerges. Thus, this study demonstrates the importance of efficient policy design in cases where the productivity of pesticides is relatively high.

2. The Carchi study

The potato production and farmer health data utilized in this analysis were collected as part of a study of the economic, environmental and human health effects of pesticides sponsored by the International Potato Center. The study was based in the Carchi Province in northern Ecuador in a highland zone 30 km south of the Colombian border. Production occurs between the altitudes of 2800 and 3400 m on steeply sloped, deep volcanic soils. Just half a degree north of the equator, there are virtually no changes in day length, little seasonal variation in temperature, and limited variation in rainfall. A detailed description of the complete study and the Carchi region can be found in the book by Crissman et al. (1997).

The cropping system is dominated by potatoes and pasture for dairy cattle, with these two crops rotated in a potato–potato-pasture cycle that takes about 2 years. Because of the equatorial Andean climate, there are no distinct planting or harvesting seasons, and potato production occurs continuously. Production data were collected in a farm-level survey on 40 farms during 1990–1992 by trained enumerators who lived in the region and made bimonthly visits to the farms. Data were collected for individual parcels, where a parcel is defined as a single crop cycle on a farmer's field. The pesticide use data are believed to be accurate, because they were collected within two weeks after a farmer made an application, so that the usual problem of data inaccuracy because of farmer recall was avoided. In addition, an ongoing quality-control process was maintained during data collection which made it possible for the enumerators to re-interview farmers to validate or correct outlying observations. Table 1 presents summary statistics for the data used in the econometric analysis of the potato production process that follows. A similar quality-control process was followed for the health data that were collected.

This physical environment is highly conducive to the soil-dwelling larvae of the Andean weevil (*P. vorax*) and the late blight fungus (*P. infestans*). Using backpack sprayers, farmers make an average of more than seven applications of pesticides to each parcel. Though a wide array of products are used by farmers in the sample, three types are dominant. The dithiocarbamate, mancozeb accounted for over 80% of total active ingredient of fungicides used to control late blight. The carbamate, carbofuran, and the organophosphate, methamidophos, accounted for 47% and 43% of all insecticide active ingredients applied. Carbofuran is used to control the Andean weevil and the organophosphates are used on foliar

Table 1
Summary statistics for Carchi potato production data

Variable	Mean	Standard deviation
Total variable cost (sucres/ha)	14.157	0.347
Expected yield (kg/ha)	9.868	0.136
Area (ha)	−0.959	0.854
Mean neurobehavioral score	−1.525	0.941
Fertilizer quantity (kg/ha)	6.309	0.401
Land preparation labor (days/ha)	2.374	0.895
Crop management labor (days/ha)	3.897	0.373
Fungicide quantity	11.905	1.426
Carbofuran quantity (kg/ha)	−0.044	1.120
Foliage pest insecticide	10.415	2.237
Fertilizer price (kg/ha)	6.448	0.181
Land preparation wage	7.656	0.306
Crop management wage	7.796	0.275
Fungicide price	−0.970	0.666
Carbofuran price	9.710	0.303
Foliage pest insecticide price	−1.222	1.225

Sample size is 219. All variables in natural logarithms except mean neurobehavioral score. Fertilizer is total N, P and K applied. Fungicide and foliage pest insecticide quantities and prices were quality-adjusted using the hedonic procedures as in the paper of Antle et al. (1994).

insect pests. Most farmers manage several fields, so that potato production and pesticide use are continuous throughout the year. An important consequence of continuous production is a year-round potential for occupational and incidental exposure to pesticides. Pesticides are not used in the pasture cycle and are seldom used in other crops that may be included in the rotation, such as legumes. Thus, a farmer's exposure to pesticides comes almost entirely from potato production. The insecticides used are neurotoxins—they kill the pest by interfering with the functioning of the nervous system. Pesticides are applied using a backpack sprayer and, in that process, the applicator's clothes often become wet with spray mix. Consequently, the major exposure route for the applicator is dermal, especially through his hands and back. Applicators appear to be aware of at least some of the risks associated with pesticide use, yet they do not use protective clothing that effectively prevent exposure, nor do they exhibit other exposure-averting behavior. Thus, the use of protective clothing in this temperate environment is similar to the evidence from the Philippines study.

To examine the health impacts of pesticide use, the health research team conducted a survey of the farm population ($n = 174$) and an age- and education-matched referent group ($n = 72$) not exposed to pesticides. All participants answered questions on pesticide use and medical problems, received a clinical examination by a field physician, completed a series of tests of nervous system function and underwent blood tests. These tests were oriented towards those effects most likely to be associated with the insecticide and fungicide exposures that the agricultural team had documented and that farm members reported over periods of days to years. Crissman et al. (1994) and Cole et al. (1998a) report elsewhere on the complex exposure pattern and the higher rates of skin problems (dermatitis), reduced vibration sensation, lower cholinesterase levels and generally poorer neurobehavioral test results among the farm population compared to the referent group.

Preliminary analyses revealed that the neurobehavioral tests demonstrated the most consistent relationship with recent use of pesticides within the farm population. Neurobehavioral tests were chosen because psychiatric literature indicated problems among those with chronic exposure to organophosphate compounds (Gerchon and Shaw, 1961), epidemiological work has documented central nervous system effects of acute poisoning episodes (Rosenstock et al., 1991) and assessments of neurobehavioral function are sensitive measures of such problems in non-clinical populations (Anger et al., 1983). We expanded on the Neurobehavioral Core Test Battery that was assessed cross-culturally and recommended by the World Health Organization (Cassito et al., 1990). Individual tests were grouped into functional sub-scales by a neuropsychologist. A battery of tests was used to assess a set of neurobehavioral skills that include attention, visual and spatial abilities, visual and auditory reaction times, and motor and psychomotor skills. The test results were standardized so that neurobehavioral status is positively related to the test score.

This neurobehavioral measure of pesticide impacts represents a significant improvement as compared to the health impairments index utilized by Antle and Pingali. The health impairment index is an ad hoc measure of several factors hypothesized to be affected by pesticide exposure, whereas the neurobehavioral index used here is derived from a standardized test which measures only the part of the organism directly affected by the neurotoxins. In addition, the sample size used in this study is nearly four times the size of the Philippine study. This direct measure eliminates most of the uncertainty of measuring health effects not originating from pesticide use.

Because of skewed distributions in test scores, we restricted the referent population by age (16–65 inclusive) and education (> 3 years) and developed linear regression prediction equations based on age and education. These restrictions removed about 20% of the population (see Cole et al. (1997b) for details). A standardized score was then calculated for each test for each farm member who met the age and education restrictions by subtracting the participants' predicted value for the test from the measured value and dividing the difference by the standard error of the estimate derived from the referent group regression. The scores were then averaged across tests in the subscale to obtain a sub-scale standardized score for each function. Finally, the arithmetic mean of the sub-scale standardized scores provided an overall neurobehavioral score for modelling purposes.

The neurobehavioral scores for the farm population were significantly lower than those of the referent non-farming population even taking account of differences in age, education and verbal intelligence level. The mean standardized score was almost one standard deviation less than the population not directly exposed to pesticides and substantially lower than that currently observable in other working populations exposed to neurotoxic substances elsewhere in the world. The mean minimums for the various functions were over three standard deviations lower, indicating substantial, clinically important deficits in the basic cognitive tasks. Such levels of dysfunction would correlate with considerable difficulties carrying out the daily tasks of running a household and making rational decisions in farm management and would be comparable to the levels found in the neuro-cognitively impaired on disability pensions in countries such as Canada and the United States. The quality of home and working life and the productivity of these farm members would thus be expected to be substantially reduced.

3. Joint estimation of the cost function and the health production function

Following the logic of the Antle and Pingali model, we posit a cost function to represent the production process. This cost function is derived from a household production model in which farmers' effective management and field labor is a function of their health. From a standard cost-minimization problem, we obtain the per-hectare variable cost function $C(y, \boldsymbol{w}, z, h)$, where y is crop yield, $\boldsymbol{w}$ is a vector of factor prices, z represents fixed factors (size of the farmer's field in the model presented here), and h is a measure of the farmer's health. This cost function exhibits the usual convexity properties with respect to y and $\boldsymbol{w}$, and is decreasing in z and h.

Following Antle and Capalbo (1994), health is assumed to be a function $h(e(x, b), \boldsymbol{c})$, where $e(x, b)$ is exposure to pesticides, x, b is a measure of averting behavior by the farmer (such as use of protective equipment and safe handling practices), and $\boldsymbol{c}$ is a vector of personal characteristics. There is little variation in averting behavior among farmers in the study presented here, so we simplify the presentation to a health production function $h(x, \boldsymbol{c})$, where h is assumed increasing and concave in x.

We utilize the log-linear approximation to the cost function,

$$\ln C = \alpha_0 + \alpha_1 \ln y + \alpha_2 \ln z + \beta_1 \ln w_1 + \ldots + \beta_n \ln w_n + \gamma h + \epsilon_1, \tag{1}$$

where ϵ_1 is an error term. Applying Shepard's lemma, it follows that $dC/dw_i = x_i^*$, where x_i^* is the cost-minimizing quantity of the ith input. For the log-linear cost function Shephard's lemma can be written as:

$$\ln(x_i^*) = \ln(\beta_i) + \ln C - \ln w_i + \epsilon_{2i}, I \tag{2}$$

where the ϵ_{2i} are error terms.

We specify the health production function as:

$$h = \delta_0 + \delta_1 c_1 + \delta_2 c_2 + \delta_3 \ln x_5 + \epsilon_3 \tag{3}$$

where c_1 and c_2 are measures of the farmer's intelligence not directly affected by pesticide exposure (c_1 is a measure of the ability to associate similar objects, c_2 is a measure of the individual's general knowledge, and both are subtests of the Ecuadorian adaptation of the Weschler adult intelligence score), x_5 is the quantity of carbofuran applied during the season on a particular field, and ϵ_3 is an error term. Recall that the toxicological literature suggests that carbofuran is the insecticide that is expected to have a significant neurobehavioral effect.

The system of Eqs. (1)–(3) is identified and can be estimated using nonlinear techniques that account for the endogeneity of cost, input quantities and health. Note that the conventional way to estimate a log-linear model with first-order conditions is to estimate the factor cost share equation with an additive error term as $w_i x_i / C = \beta_i + \epsilon_{2i}$. Eq. (2) is equivalent to estimating the cost share equations in the multiplicative error form $w_i x_i / C = \beta_i \exp(\epsilon_{2i})$. This multiplicative error model is attractive because it is consistent with the log-linear, constant-elasticity specification of factor demand equations with additive errors, and because it fits the data well in this case.

The system (Eqs. (1)–(3)) is nonlinear in the parameters because of the $\ln(\beta_i)$ terms in Eq. (2). The nonlinear three-stage least squares estimation method in the SAS 6.10 Model Procedure was used to estimate jointly the system of Eqs. (1)–(3). This is a system of eight equations: the cost function (Eq. (1)); the six first-order conditions corresponding to fertilizer (input 1), land preparation labor (input 2), crop management labor (input 3), fungicides (input 4), carbofuran (input 5), and foliage pest insecticides (input 6); and the health production function (Eq. (3)). The parameter estimates with t-statistics in parentheses are:

$$\begin{aligned}\ln C = \underset{(-1.13)}{-2.294} + \underset{(6.81)}{1.397\ln y} - \underset{(-2.93)}{0.066\ln z} + \underset{(59.30)}{0.247\ln w_1} + \underset{(16.76)}{0.016\ln w_2} + \underset{(45.30)}{0.085\ln w_3}\\ + \underset{(15.45)}{0.040\ln w_4} + \underset{(13.52)}{0.011\ln w_5} + \underset{(9.27)}{0.007\ln w_6} - \underset{(-3.45)}{0.103\,h}\end{aligned}$$

$$h = \underset{(-9.87)}{-3.074} + \underset{(2.04)}{0.046\,c_1} + \underset{(3.46)}{0.177\,c_2} - \underset{(-3.25)}{0.247\ln x_5}.$$

As explained by Antle et al. (1994), it is important in estimating production models with pesticides to account for the large number of different chemicals that are used by farmers that exhibit varying degress of efficacy in controlling pests. To control for varying pesticide quality, the fungicide quantity and price and the foliage pest insecticide quantity and price were quality adjusted using the hedonic procedure described by Antle et al. (1994). Expected yield y was estimated as the predicted value of a regression of actual yield on the quantity of seed potato sown, a set of dummy variables indicating soil types and precipitation, the altitude of the field, and its area.

4. Implications

The parameter estimates of the cost function are all statistically significant and indicate decreasing returns to scale and increasing returns to field size, as expected. The essential role that pesticides play in crop production is indicated by the positive and significant coefficients on the fungicide, carbofuran and foliar insecticide variables. Output-constant own-price elasticities of demand (equal to $\beta_i - 1$) range from about -0.75 for fertilizer to about -1.0 for foliage pest insecticides. The coefficient on the neurobehavioral health variable is statistically significant at all conventional levels, and its negative sign indicates that farmers with higher neurobehavioral function obtain lower cost of production per hectare, and thus, higher productivity, as hypothesized. The magnitude of the coefficient indicates that the elasticity of cost with respect to health is about -0.15. In comparison, the estimates of the elasticity of cost with respect to health obtained by Antle and Pingali in their study of two rice producing areas of the Philippines ranged from -0.13 to -0.36.

The health production function parameters are highly significant and indicate, as expected, that farmers with higher verbal intelligence scores (c_1 and c_2) also have higher neurobehavioral function. The total quantity of carbofuran applied during the season has the hypothesized negative effect on neurobehavioral function.

Combining the cost function and the health equation, we see that higher neurobehavioral function of farm managers lowers average production cost, while increased use of the insecticide carbofuran increases crop production but lowers neurobehavioral function. To assess the net effects of a change in carbofuran use, we simulated the model over a range of carbofuran prices (from 50% below the observed mean price to 200% above it). To investigate the effects of the efficiency of alternative restrictions on pesticides, the simulation was performed with the tax imposed on carbofuran alone and with it imposed on all pesticides. To investigate the importance of the health

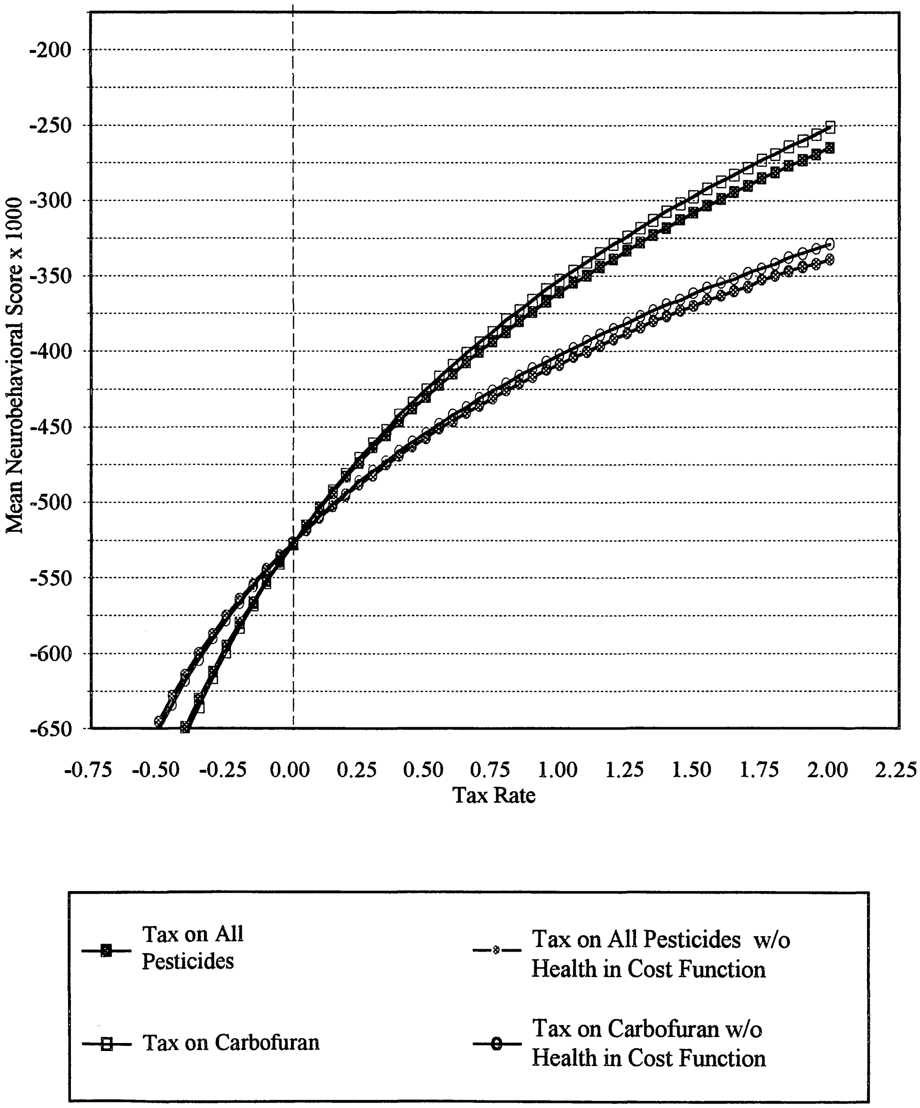

Fig. 1. The simulated effects of the pesticide tax on farmer health as measured by the mean neurobehavioral score.

effect in the cost function, we also simulated the system (Eqs. (1)–(3)) that was estimated without the health variable in the cost function (i.e., with $\gamma = 0$). The results of the simulations are presented in Figs. 1 and 2.

Fig. 1 shows the simulated effects of the pesticide tax on farmer health as measured by the mean neurobehavioral score. As expected, health is monotonically increasing in the tax rate because pesticide use is negatively related to the tax rate, but the slope of the relationship is higher when the effect of health on productivity is taken into account. This figure also shows that there is little difference between a tax on carbofuran only and a tax on all pesticides in terms of the health outcomes. This is because there is little substitution between carbofuran and other pesticide inputs.

Fig. 2 shows the effect of the pesticide tax on average variable cost of production. Here, we see several interesting results emerge. First, when a con-

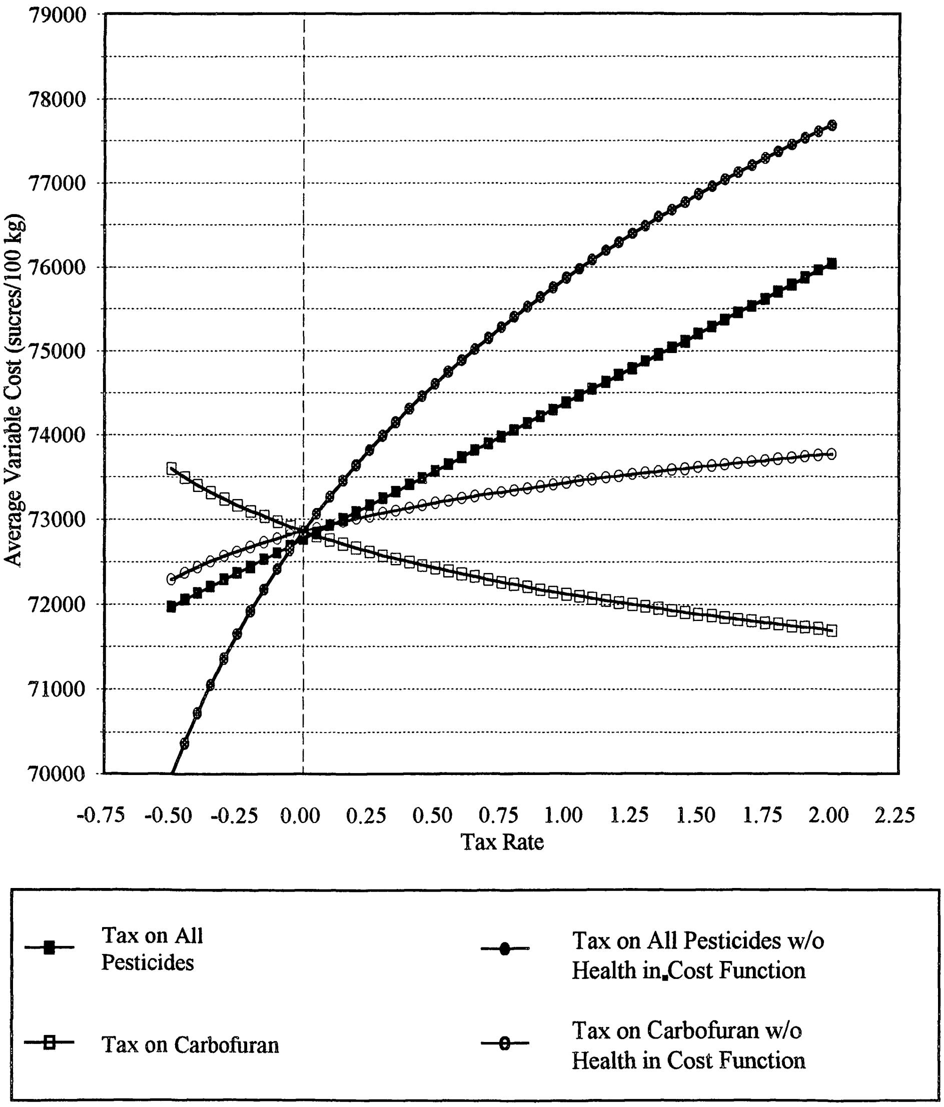

Fig. 2. The effect of the pesticide tax on average variable cost of production.

ventional specification of the cost function is used with health excluded from the cost function, a tax on carbofuran or a tax on all pesticides increases the average variable cost of production, as economic theory predicts. Second, when health is included in the cost function, a tax levied on carbofuran alone results in a *negative* relationship between the tax rate and average cost. This result occurs because the positive effect of a higher pesticide price is more than offset by the cost-reducing effect of improved health. This result is similar to the Antle and Pingali finding that a pesticide tax targeted at insecticides in rice production would increase productivity. However, when a tax on all pesticides is used, a positive relationship emerges because the effect of the tax on cost now exceeds the effect of health in the cost function.

The clear policy implication of these findings is that reducing carbofuran use is a win–win proposition: farmers would be both healthier and more productive if carbofuran use were reduced, because the productivity gains from improved health outweigh the negative productivity effects of reduced pesticide use. However, a policy to reduce all pesticide use would be less efficient and would result in a tradeoff between health and productivity.

In concluding, we note that a pesticide tax is used in the simulations to illustrate the effects of changing pesticide use. Taxes are representative incentive-type policies. Also, available to policy makers are several types of regulatory and other policies. For example, in the United States, high-risk pesticides can only be applied by trained pesticide applicators. Many countries also restrict the availability of certain environmentally damaging or dangerous pesticides, or include regulations regarding on-farm use of risky pesticides on the product label. There are also important technology and education policy options, including integrated pest management, the development of late-blight resistant varieties, and programs to promote the safe use of pesticides and the use of protective clothing. These policies could improve productivity and the health of the farm population without imposing the productivity losses that could be associated with reduced pesticide use.

Trade and related exchange rate policies also could have a significant impact on pesticide use, environmental quality, productivity and health (Antle et al., 1996). Ecuador's exchange rate policies have effectively subsidized the importation of pesticides such as carbofuran by about 30% (Lee and Espinosa, 1998). Because this policy change would be equivalent to a uniform tax on all types of pesticides, the analysis presented here implies that the elimination of this subsidy would reduce all types of pesticides and improve health, but could adversely affect productivity.

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