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Pesticide use in Brazil in the era of agroindustrialization and globalization

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ABSTRACT. This study examines the trend in pesticide use in Brazil in the 1990s in the context of agroindustrialization and globalization (trade liberalization). It also seeks to document the environmental costs and human health hazard associated with pesticide use in Brazil. Results from time series data indicate that agricultural trade liberalization has led to increased pesticide use in Brazil, particularly in export crops. Results from cross-section municipality-level data point to higher incidence of pesticide use in municipalities with high income, higher levels of education, large-size farms, predominance of export crops, and with high prevalence of sharecropping. Finally, the study finds that Brazil's agricultural growth in the era of trade liberalization has been clouded by serious human health problems and environmental damage caused by pesticide use.

1. Introduction

Concerns about the environmental effects of agricultural trade liberalization have prompted a number of studies in recent years. The anticipated environmental consequences are multi-dimensional (some detrimental and some positive). However, most environmentalists agree that there are certain serious environmental costs to be concerned about, especially in terms of chemical input use (Islam, 1993; Anderson, 1998; Pingali, 1999). Examples of these latter costs relate to water and air pollution as

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well as to soil degradation. In addition to the environmental costs, there are also acute and chronic human health hazards that need to be considered.

Although some of the literature has focused on the theoretical aspects of links between agricultural trade liberalization and pesticide use, empirical evidence on this subject remains rather thin, especially in the case of developing countries. One of the primary reasons for this absence of analysis has been the lack of reliable data on chemical input use in developing countries.

This paper has two objectives. The first is to examine the trend in pesticide use in Brazil in the 1990s in the context of globalization (trade liberalization) and agroindustrialization. The second objective of the study is to document the environmental costs and human health hazards associated with pesticide use in Brazil.

The paper contributes to the literature in three ways. First, although a number of authors (e.g., Bellotti, Cardona, and Lapointe, 1990) have studied the trend in pesticide use in Brazil, this study is the first to document recent changes in pesticide use in Brazil as related to agricultural trade liberalization. Second, to the best of our knowledge, the paper uses municipality-level data to study the spatial variability of pesticide use. Third, we present further evidence of the negative externalities associated with pesticide use in Brazil.

Drawing on a wide range of data, the paper concludes that, despite growing awareness of environmental degradation and human health hazards, pesticide use in Brazil is increasing rapidly in the era of agricultural trade liberalization. This primarily stems from the fact that at the farm level, in most cases, there are greater private benefits of pesticide use than private costs, and that this equating of marginal benefits and marginal costs does not internalize the true social costs of pesticide use. The resulting marginal external cost borne by society appears to be concentrated in areas where large commercial operations exist, and in socio-demographic areas characterized by high income and education.

The paper is organized as follows. In section 2 we introduce and review the literature dealing with the impact of agricultural trade liberalization on pesticide use. In section 3 we outline pesticide use trends in Brazil in the 1990s as related to agricultural trade liberalization. In section 4 we develop the rationale for pesticide use in Brazil. In particular, the analysis exploits municipality-level data to examine the spatial variability of pesticide use. In section 5 we present evidence of health hazards and environmental costs associated with pesticide use. In section 6 we conclude and provide some brief implications of the findings.

2. Agricultural trade liberalization and pesticide use: theory and evidence

In theory, one nation will engage in trade when there is an economic advantage to buying a good from another whose factor endowments allow for the production of the good at a lower cost. In the absence of any domestic trade distortions, this exchange is Pareto optimal. However, as is often the case, many domestic agricultural policies are targeted at protecting domestic producers from foreign competition, leading to trade distortions that tilt the balance in favor of one country. For example, in many developing countries policies affect producer costs through taxes to keep consumer prices down, through input subsidies to increase crop yields (Runge, 1992), or subsidies to partially compensate producers who grow crops destined for export using advanced and costly techniques acceptable to international standards (May and Bonilla, 1997). Domestic policy makers may also combine these protectionist activities with other tools designed to further societal interests or a range of environmental goals (e.g., pesticide import restrictions).

Policies that distort input and output prices from their unrestricted equilibrium drive a wedge between private and social costs, representing an overall welfare loss to society. Should such price distortions also lead to environmentally unsound practices at the farm level, these societal losses are further compounded (e.g., pesticide subsidies leading to overuse).

Agricultural trade liberalization initiates change predominantly by affecting the prices of products and inputs through reduction in tariffs, relaxation of quantitative restrictions on products or inputs, and harmonization of technical standards (Ervin and Fox, 1998). Although the impacts are multi-faceted and complex to decompose, our primary interest is the impact on pesticide use. Pesticides, a primary factor of increasing yield, are affected by trade liberalization, as tariffs and subsidies are reduced and import restrictions lifted. Generally, they give rise to large economic benefits including increased yields, production cost savings, reduced need for manual labor to control weeds, as well as stabilization of food supplies (OECD, 1997). At the same time, pesticides can also give rise to health hazards and environmental damage.

The consequences of trade liberalization on the environment have guided research at many levels, including global (Andersen and Strutt, 1996; Fredriksson, 1999; OECD, 2000; Runge, 1992), national (Abler, Rodríguez, and Shortle, 1999; Antle and Capalbo, 1998; Antle *et al*., 1996; Beghin *et al*., 1997), regional (Williams and Shumway, 2000), and the local level (Antle and Capalbo, 1998; Antle *et al*., 1996). Surprisingly, the impacts of agricultural trade liberalization on pesticide use has not been researched sufficiently. Pesticide-related impacts are local in nature due to the complex interactions between pesticide prices and the observability of corresponding health and environmental impacts. However, agricultural trade policy, or competitiveness, is usually analyzed at the national or international level.

It is possible to draw some inferences on pesticide use behavior from the link between trade liberalization (or trade) and the environment, in general. Many writers (e.g., Andersen, 1992; Ervin, 2000; Runge, 1992; Fredriksson, 1999; de Boer, 1994) have indicated that the impact of trade liberalization on the environmental welfare of countries is ambiguous to the extent that it depends on the magnitudes and sometimes conflicting directions of certain effects. These include the scale effect (openness gives rise to greater economic activity, thus raising the demand for inputs, etc.), the output composition effect (changes in the relative size of the economic sectors) and the technique effect (changes in production method). It can be then argued that the impact of trade liberalization on the environment is thus an empirical matter.

Williams and Shumway attempt to evaluate the potential impacts of the North America Free Trade Agreement (NAFTA) on agricultural chemical use in Mexico and the United States of America. They examine the potential changes in real farm income and real marginal values as well as aggregate use of fertilizer and pesticide usage by the American and Mexican agricultural sectors following full implementation of NAFTA and associated changes in domestic farm policy (2000: 183). Simulation results reveal the following likely impacts on US and Mexican agriculture in the year 2005. Fertilizer and pesticide use in the United States is expected to increase by more than one-third and one-half, respectively, leading to increased problems of water pollution and chemical residue in food. In Mexico, marked increases in fertilizer use and decreases in pesticide use are expected. While increased fertilizer use will lead to increased surface water and groundwater nitrate contamination, decreased pesticide use will give rise to improved water quality and less residue in food.

Abler, Rodríguez, and Shortle (1999) using a CGE model with eight environmental indicators (e.g. pesticides) for Costa Rica find that trade liberalization scenarios (e.g. tariff caps and cuts in export subsidies) will increase pesticide use mainly in response to expanded export crop production. Their findings suggest that, as the liberalization effect gains strength (reductions in tariffs), the resulting impact will be an increased flow of trade, but at a higher environmental cost. A similar result was found by Antle *et al.* (1996) in their farm-level simulation of the environmental effects of trade liberalization in Ecuador, where the removal of import subsidies on pesticides jointly with improved relative prices for potatoes would result in increased use of pesticides and to changes in crop rotations favoring potato production. In export-oriented regions, it is quite often the case that farm gate prices will tend to shift the composition of crops grown, or even the frequency of rotations. In addition to the incentives for crop composition, the availability and price of pesticides may dictate the decision to use pesticides. Repetto (1985), in a study of the impact of pesticide subsidies in nine developing countries, concluded that: 1. by lowering the financial cost (increased risk reduction) subsidies raise the expected net returns from heavier and more frequent pesticide applications; 2. subsidies induce farmers to substitute chemicals for non-chemical methods of pest management, such as integrated pest management; and 3. subsidies are lost revenue for governments to use in monitoring, training, regulation, research, and extension for safe and effective pest control.

To the extent that trade liberalization distorts the prices of crops and pesticides, this will affect farmer's decision to use pesticides. As domestic trade restrictions are relaxed, domestic prices will respond and the decisions made will have their attended environmental consequences. We begin the next section by describing the market conditions in Brazil in the decade of trade liberalization. By assessing the specific impacts on prices and flows of goods, we attempt to gain an understanding of the impact of trade liberalization in Brazil.

3. Agricultural trade liberalization and pesticide use trends in Brazil

Brazil in the 1990s provides a good test case of the impact of trade liberalization on pesticide[1] use since Brazil greatly simplified its trade regime, eliminating most quota restrictions, reducing and removing export taxes and quotas, and reducing import taxes on farm inputs (Valdés, 1996; Brandão and Carvalho, 1991).[2] Moreover, the successful establishment of the new Southern Common Market, MERCOSUR, on 1 January 1995, has eliminated most tariffs on products traded among its members (Argentina, Brazil, Chile, Paraguay, and Uruguay). About 80 per cent of all products traded today have duty-free status within the bloc (de Brey and Tsigas, 1997; Laird, 1997). According to Baumann, Rivero, and Zavaltiero (1998: 1971), 'the trade liberalization process reached its height in the first quarter of 1995 in terms of the average level of tariffs and their degree of dispersion'. Thus, trade liberalization has been a gradual process rather than an immediate, one-time event.

Figure 1 indicates that the trade of agricultural commodities grew to record levels in Brazil during the period of agricultural trade liberalization. Indeed, between 1990 and 1997, Brazil's production of export crops (in

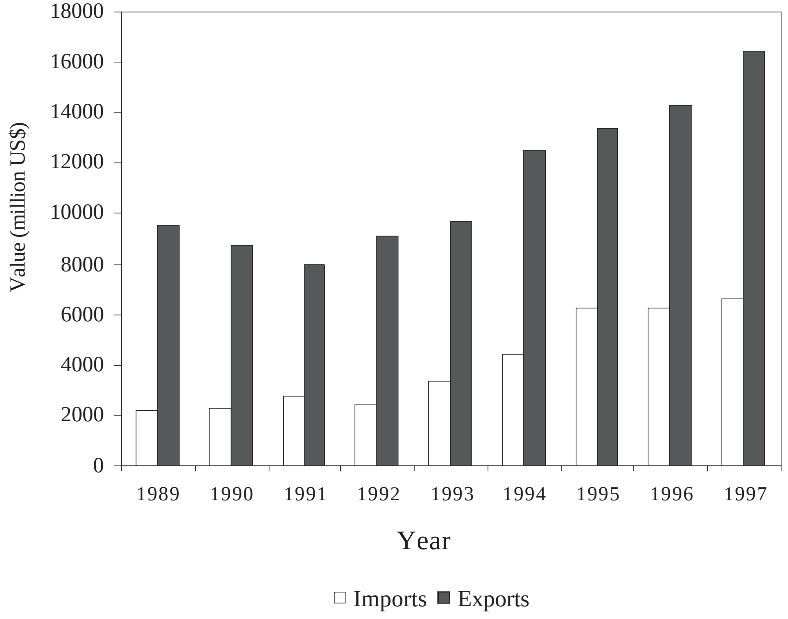

Figure 1. *Brazilian agricultural exports and imports*
Source: FAO, 1999.

[1] Pesticides, in the sense of this paper, consist of herbicides, fungicides, insecticides-acaricides, and other minor categories (see also Mannion, 1995; Chiras, 1991; Bellotti, Cardona, and Lapointe, 1990).

[2] 'Traditionally, Brazil's elaborate Minimum Price Program was accompanied by credit subsidies and a complex trade regime that included both quantitative restrictions an imports and exports, and import tariffs' (Valdés, 1996).

metric tons) increased by 29 per cent and the value of Brazilian agricultural exports nearly doubled, reflecting a switch to higher-valued products. The value of net exports of agricultural products increased from US$6.5 billion to US$9.8 billion. The increase in exports is principally due to export increases in soybeans, sugar, coffee, cocoa, and cotton. In addition, Brazilian agro-industries also recorded a steady growth during this period (IBGE, 1995).

Are these increases in agricultural net exports mainly attributable to trade liberalization? Valdés (1996: 2) noted that for Latin America, in general, 'the initiation of trade liberalization coincided unexpectedly with a fall in border prices of most agricultural commodities (beyond their long-term trend) and an appreciation of exchange rates'.[3] Consequently, given the general decrease in prices, the increased value of agricultural sales is attributable to increases in quantities sold. That is, agricultural trade liberalization resulted in increased agricultural production, mainly through its effect on the major factors of agricultural production.

Farmers seeking to expand their production also depend on input prices. In the period of major tariff reductions,[4] real pesticide prices fell dramatically to a low in 1996 allowing for potential productivity gains (figure 2).

Commenting on increased productivity, Petit, in his foreword to Farah (1994), pointed out the following observation for developing countries:

> When chemical pesticides started to be used on a large scale, they significantly contributed to the enhancement of agricultural production and the suppression of many insect-transmitted human diseases. Indeed, as the food and fiber requirements of growing population increased, coupled with the need to generate foreign exchange, increasing agricultural productivity became a vital national concern. Thus, an important component of government strategies to increase agricultural production has been the encouragement of pesticide use since pests and diseases were one of the major causes of yield losses. This was coupled with the adoption of economic policies that facilitated the access to, and the domestic industry of, pesticides.

[3] In Brazil, for example, real agricultural border prices registered a cumulative percentage decrease of 10.2 over the period 1990–1993 in contrast to a cumulative percentage increase of 41.3 over the period 1986–1989. The same tendency was observed for real domestic prices for exportables. At the same time, the real exchange rate appreciated by 54.8 per cent over the period 1990–1993 in contrast to 12.6 per cent over the period 1986–1989 (see Valdés, 1996: table 2a, p.12).

[4] In 1988, the Brazilian government began radical reform of the tariff system. For the fine chemical industry, which included the pesticides industry, a uniform tariff of 60 per cent was applied. According to Frenkel and da Silveira (1996) the tariff used to be greater than 80 per cent. After 1990, the government decided to effectively reduce the average tariff level and phase out non-tariff barriers. Through the period until 1994, the schedule of tariff changes were from 60 per cent to 30 per cent for technical products produced in the country and a level tariff of 20 per cent for formulated products.

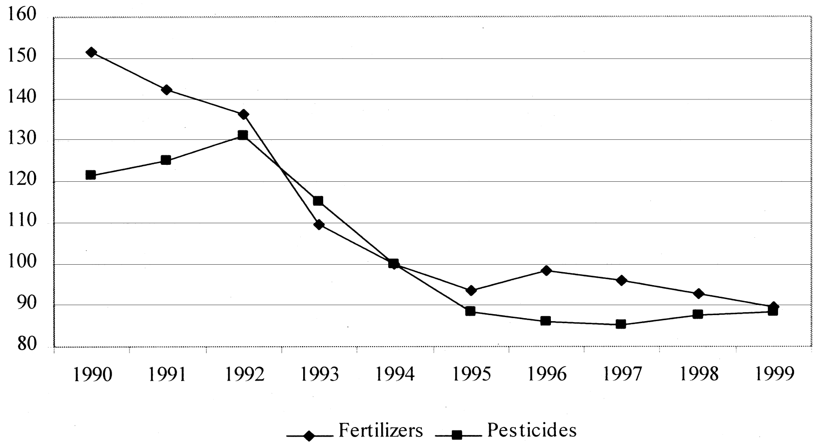

Figure 2. *Index of Prices Paid by Producers, IPP (Aug. 1994 = 100)*
Note: The index is computed as a weighted average of pesticides, fertilizers and other inputs and services. IPP is discounted by the General Price Index (IGP-DI).
Source: FGV, 2000.

Petit's characterization of developing countries is also relevant in the case of Brazil. In fact, Brazil is promoting the use of pesticides[5] to expand agricultural frontiers[6] and to increase output per hectare of land. In Brazil, pesticide use in general is increasing and, as recorded by Associação Nacional de Defensivos Agricolas (ANDEF), pesticide sales more than doubled between 1990 and 1998 (figure 3).[7] During this period, herbicide sales dominated pesticide sales, accounting for 54 per cent of total use followed by insecticides-acaricides (28 per cent) and fungicides (16 per cent).

The rising trend in pesticide use in Brazil has been further confirmed by information on the quantity of pesticide use compiled and reported by Sindicato Nacional de Industria de Defensivos (SINDAG). Data from SINDAG on the nation-wide quantity of pesticide use indicates that use in Brazil increased from 61,820 tons of active ingredients[8] in 1989 to 113,933 tons in 1997. Among pesticides, the increase in the quantity of herbicides was from 25,741 tons to 61,885 tons, insecticides-acaricides from 21,861 tons to 26,053 tons, and fungicides from 14,089 tons to 17,369 tons. Brazil currently uses 655 different varieties of herbicides, 815 insecticides, 343

[5] Pesticides have always been subsidized in Brazil (Farah, 1994).

[6] Expansion of 'less favorable areas' in crops such as soybeans, sorghum, wheat, pulses, rice, maize, cacao, and citrus.

[7] In 1996, Brazil accounted for 40 per cent of the total consumption of pesticides in Latin America (*O Estado São Paulo*, 1996)

[8] An active ingredient is the base elemental chemical in the pesticide. Active ingredients are combined with other chemicals or 'carriers' to create a formulation designed for a specific use.

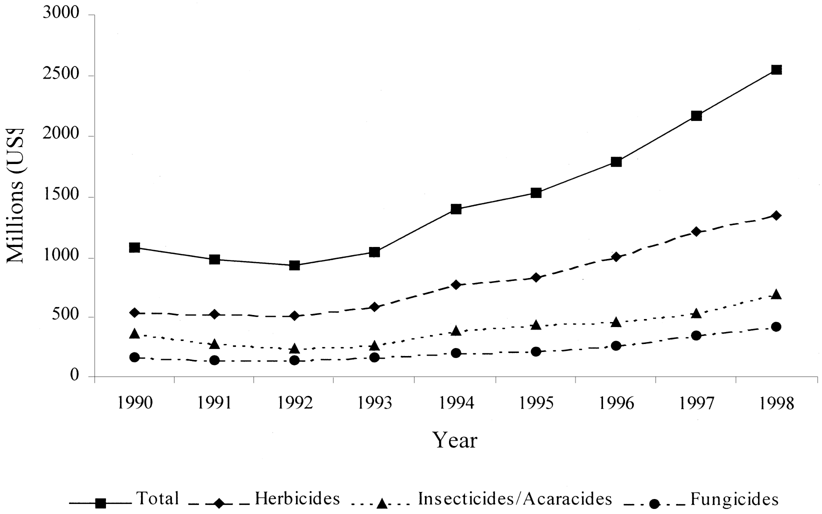

Figure 3. *Pesticide sales in Brazil*
Source: ANDEF, 1998.

fungicides, and 136 other pesticides to increase agricultural production (AGROFIT, 1998).

Pesticides have been used to a greater extent on export crops than on non-export crops. Indeed, as table 1 indicates, in 1997 while the major export crops received 66 per cent of pesticides, the non-export crops only used 26 per cent. In addition, the distribution of the quantity of pesticide use (per cent) by major export crops reported by SINDAG (table 1), reveal that the skewing of pesticide use by export crops is particularly marked, with soybeans, sugarcane, tobacco, cotton and fruits accounting for 70 per cent of insecticides-acaricides, 62 per cent of herbicides, and 27 per cent of fungicides during 1997. As far as other crops are concerned, corn and vegetables dominated pesticide use with 19 per cent of total pesticide use in 1997. Vegetables had the highest fungicide use (37 per cent) of all crops. Overall, throughout the 1990s, herbicide sales dominated the Brazilian pesticide market, with its principal users being soybeans (37 per cent), sugarcane (20 per cent) and corn (19 per cent). Soybean production used more pesticides overall, in total 28 per cent, than any other crop followed by fruits (17 per cent), sugarcane (11 per cent), and corn (11 per cent) in 1997.

A somewhat more formal quantitative impact of trade liberalization on pesticide use is illustrated by running a regression over the period 1983–1997 using pesticide use,[9] expressed in tons of active ingredient,[10] as

[9] One shortcoming of this regression analysis was the lack of sufficient data for the period 1992–1996 (1997 was available). Thus, in performing this regression, it was necessary to generate data for the missing years. The latter missing data were generated following the trend in pesticide sales for which we have data for 1990–1998.

[10] We use active ingredients to isolate the price effect.

Table 1. *Distribution of pesticide use (in %) in 1997 among the major crops of Brazil*

	Herbicides	*Insecticides/Acaricides*	*Fungicides*	*Total pesticides*
Major export crops				
Soybeans	37	16	2	28
Fruits[1]	3	44	23	17
Sugar	20	1	< 1	11
Coffee	4	6	13	5
Cotton	2	8	< 1	3
Tobacco	< 1	1	1	< 1
Cocoa	< 1	< 1	1	< 1
Subtotal	66	76	39	66
Other crops				
Corn	19	3	< 1	11
Vegetables[2]	1	8	37	8
Rice	7	< 1	1	4
Wheat	2	< 1	2	2
Subtotal	30	12	39	26
Rest	4	12	21	9
Total	100	100	100	100

Note: Numbers may not necessarily add to 100 due to rounding.
[1] Includes citrus, apples, peaches and grapes.
[2] Includes potatoes, tomatoes, onions and beans.
Source: SINDAG (1997).

the dependent variable[11] and a variable that captures the gradual trade liberalization effect. The latter variable is a 'dummy-count' variable which takes on a value 0 before 1990 and 1 for 1990, 2 for 1991, 3 for 1992, 4 for 1993, 5 for 1994, and 6 for 1995 and afterward.

Table 2 presents the results of the exercise. The regression results indi-

Table 2. *Agricultural trade liberalization and pesticide use in Brazil: 1983–1997*
Dependent variable: change in pesticide use in tons of active ingredients

	Coefficient	*Standard error*	*t-statistics*
Constant	−1,264.052	3,517.690	−0.359
TR	2,617.084*	1,067.110	2.452
	$R^2 = 0.316$**		
	DW = 2.047		

Note: $DH_1 = C + b * TR_1 + u_1$ is the regression of interest where DH is the first difference of pesticides, C is the constant term, u is a well-behaved error term and TR is the variable for trade liberalization, which takes on a value 0 before 1990, 1 for 1990, 2 for 1991, 3 for 1992, 4 for 1993, 5 for 1994 and 6 for 1995 afterwards. Method of estimation: Least Squares Method.
* and ** mean significant at the 1% and 5% levels, respectively.
Source: ANDEF (1998) for pesticides (in tons of active ingredients). We generated missing data for 1992–1996 following the trend in pesticide sales for which data are available.

[11] We use the first difference of pesticide use instead of the level to avoid the problem of spurious regression.

cate that pesticide use has been increasing by a multiple of about three thousand tons of active ingredients throughout the 1990s. The fit of the regression is significant and 32 per cent of the variation in pesticide use is explained by the regression. Thus, the gradual process of agricultural trade liberalization in the 1990s appears to have led to increased use of pesticides in Brazil.

4. Pesticide use trends: farm-level decision

The rationale for pesticide use

The extent of pesticide use in a region rests primarily on the concept of minimizing production risk, or reducing yield variance, and a farmers' risk attitude (Rola and Pingali, 1993). In minimizing risk, the farmer will equate marginal private benefits with marginal private costs to maximize net private benefits. The farmer's private benefits of using pesticides are typically increases in yield, risk reduction in fertilizer use, risk reduction in crop output and substitution of labor (labor cost savings). Although increases in crop yield is the 'raison d'être' of most pesticides, reduction in yield variance is the most important function of insecticides and fungicides and labor cost savings is the main instrument for herbicides to boost crop profitability. The private costs are all farmers' production, labor and capital costs related to pesticide use.[12] If the private benefits of using pesticides exceed the private costs, then farmers have an incentive to engage in pesticide-using activities. Over the last decade, the fall in real pesticide prices lowered producer costs and increased the benefits to use. The increase in sales and usage, as well as the prevalence of health impacts, further substantiates the claim that the benefits to use outweigh the costs.

Municipality-level pesticide use patterns

Geographical distribution

Brazil is a vast area characterized by significant variability of climate, crops, and agricultural production systems. The pattern of pesticide use varies by region and largely depends on topography, climate, size of agricultural activities, type of crops, and farming processes (Bellotti, Cardona, and Lapointe, 1990). In order to address the regional diversity of Brazil, we utilized data from the 1996 agricultural census conducted by Fundação Instituto Brasiliero de Geografia e Estatística (IBGE).

Actual data on application (quantity) of pesticides at municipality level were not available in Brazil. However, in the 1996 agricultural census, a question was asked as to 'whether the agricultural holding used pesticides or not'. In response, 96 per cent of the municipalities (4,713 out of 4,909) and 2.4 billion hectares of agricultural land reported pesticide use in 1996. The agricultural area reporting application of pesticides across municipalities varied from 0–21.4 million hectares with a median of 64,573 hectares.

Using responses on total acreage and acreage using pesticides by crop, it was possible to construct the proportion of agricultural area reporting

[12] These costs are also referred to as the farmers' 'perceived' costs, where the external effects on health and the environment have not been internalized. Thus actual private costs should be 'perceived' costs plus external costs.

pesticide application for 4,909 municipalities of Brazil. This proportion of agricultural area with pesticide application when plotted on a municipality-level map revealed wide geographical variation. In figure 4, the geographic distribution of the proportion of agricultural area reporting pesticide application is far from random. There appears to be a high concentration of land with pesticide application in the Center South, and Northeastern coastal regions of Brazil. In particular, this proportion is strikingly higher in the states of Paraná, Mato Grosso do Sul, Santa Catarina, São Paulo, Goiãs, Mato Grosso, and Rio Grande do Sul. Fifty-five per cent of all reporting municipalities in Paraná, 48 per cent in Mato Grosso do Sul, 42 per cent in Santa Catarina, 41 per cent in São Paulo, 34 per cent in Goiãs, 34 per cent in Mato Grosso, and 34 per cent in Rio

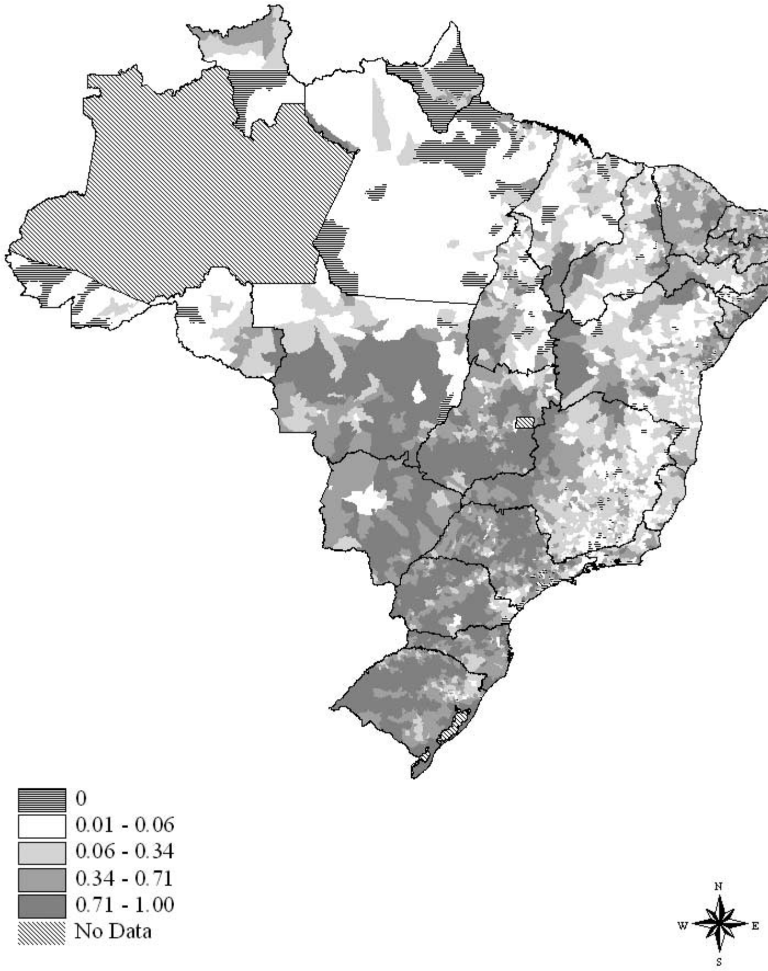

Figure 4. *Proportion of agricultural land using pesticides*
Source: IBGE, Censo Agropecuario, 1996.

Grande do Sul reported pesticide use on more than 75 per cent of their agricultural land. Cumulatively, these seven states accounted for 81 per cent of all pesticide use in Brazil during 1997 (SINDAG, 1997).

Determinants of municipality pesticide use

The municipalities of Brazil are quite varied in land-use patterns, crop production, relative farm size, farm ownership distribution as well as income and education. In order to capture the heterogeneity among municipalities, data on land use, crop patterns, conservation practices, farm size or scale, and ownership were drawn from the agricultural census administered by IBGE. We summarize these below:

- *Land use*: The nature of economic activity should influence the decision to use pesticides. Operations which are more crop and livestock oriented (prone to a larger variety of pests and diseases) may lead to an increase in the propensity to use pesticides. From the census we were able to identify eight different land-use patterns, including permanent and temporary crops, seedling production, and livestock operations.
- *Crop patterns*: Analogous to land use, the type of crop produced will also dictate the variety and amount of pesticides used. In Brazil, crops such as soybeans, corn, sugarcane, coffee, rice, beans, and cotton are known to be large users of pesticides; all are major export crops. Thus we expect a large positive correlation between crops which are prone to pests and diseases and the propensity to use pesticides. Seventy-six different crops were used from the census.
- *Size class*: Scale economies in production should also be reflective of use. In general, larger, more capital-intensive operations should be positively correlated with use. In addition, large-scale commercial operations have been known to use particular pesticides to enhance the appearance of the agricultural product, either for local markets or bound for export. Agricultural holdings were classified into five size classes: less than 10 hectares, 10–100 hectares, 100–1,000 hectares, 1,000–10,000 hectares, and greater than 10,000 hectares.
- *Ownership*: Ownership information was classified into four categories: individually owned, under rental arrangement, under sharecropping, and squatters. Effective environmental stewardship has always been largely affected by the incentive structure signaled by property rights and thus land tenure. It is reasonable to expect that, if land were owned outright, economic agents would behave in a manner that is consistent with their long-term interest and decrease the use of hazardous pesticides which may cause irreversible ecosystem damage. As this tenure arrangement 'loosens' (e.g., share cropping, renting), agents may act more carelessly and increase use to boost short-term productivity yields.
- *Conservation tillage*: One generally accepted method of conserving the long-term sustainability of soil properties, and hence crop yield, is the practice of conservation tillage. Conservation tillage affects pesticide use through its effect on fertilizer use, soil quality, and the growth of vegetation. The presence of this activity may, in fact, be associated with

more or less pesticide use, however, recent evidence from the US shows that, while adoption of conservation tillage may indicate farmer concern about erosion, it also tends to result in more weeds, which may result in greater herbicide use. Census information recorded that, on average, 25 per cent of the agricultural area was practicing conservation tillage.

- *Input and crop prices*: Market prices for crops and inputs are important factors in the production decision and therefore pesticide use. As crop prices rise, farmers increase production and, in turn, may use more pesticides in the process. As relative input prices rise, the impact on pesticide use can either be negative or positive, depending on the substitutability and complementary of other inputs.
- *Per capita income and education*: The relationship between per capita income and the propensity to use pesticides has two possible effects. Firstly, as incomes rise, purchases of pesticides may actually increase, leading to an increase in use. A second possibility is that as incomes rise there may be a general consensus by the public for a cleaner environment, and greater social pressure to move away from pesticide use. The dominant of these two effects will dictate either a negative or positive relationship with the propensity to use pesticides. Education, interpreted as a measure of a farmer's literacy as well as potential environmental awareness, should also be particularly important, where higher levels of education would translate into decreases in use. The 1991 demographic census of Brazil provided information on the median income of the head of the household, a proxy for municipality-level per capita income. The percentage of population with secondary level education from IBGE, Contagem da População (count of population) 1996, has been used as a measure for the level of education. The median income of the head of the household varied from 544 to 770,515 (in 1991 Brazilian Reals), and the proportion of population with secondary level of education varied between 0 per cent and 99 per cent.

In the absence of direct information on quantity of pesticides used by municipality, we focus on the proportion of agricultural area with pesticide application (PROPUSE) as a measure of propensity to use pesticides in a municipality.[13] In light of Mullen, Norton, and Reeves, (1997), we estimated the following equation[14] for pesticide use across Brazilian municipalities

$$\begin{aligned} PROPUSE_i = \alpha_0 &+ \sum_j \alpha_{1j} OWN_{ij} + \sum_j \alpha_{2j} SIZE_{ij} + \sum_j \alpha_{3j} LUSE_{ij} \\ &+ \alpha_4 CONSERV_i + \sum_j \alpha_{5j} CROP_{ij} + \alpha_6 INCOME_i + \alpha_7 INCOME_i^2 \\ &+ \alpha_8 EDUC_i + U_i \end{aligned} \tag{1}$$

[13] Estimation of alternative measures of municipality-level pesticide use and pesticide intensity (average pesticide application per hectare) by combining nationwide pesticide application for major crops (SINDAG) with agricultural census data on acreage using pesticides by crop (IBGE) is the subject of future research.

[14] Price variables are excluded since data are not available at the municipality level in Brazil.

where the explanatory variables are farm ownership types (*OWN*), size-class of farms (*SIZE*), land-use patterns (*LUSE*), conservation tillage practiced by farms (*CONSERV*), crop pattern (*CROP*), per capita income (*INCOME*), and education attainment (*EDUC*); i stands for the municipality (i =1,2,…,4909), j stands for the jth category of the right-hand side variable of interest, α_0 is the intercept term and U is a random error term.

Equation (1) was estimated using least squares.[15] Table 3 presents a summary of our regression results.[16] The robust F-statistic and adjusted R^2 reveal that the model variables have significant explanatory power. The observed propensity to use pesticides in a particular municipality is the outcome of several factors: the pattern of farm ownership, the distribution of size of agricultural holdings, the pattern of land use, conservation practices, the choice of crops, average income, and education. Overall, the size class variables suggest that municipalities with relatively smaller farms have a significantly lower propensity to use pesticides. An increase in the proportion of establishments in the 10–100 hectare size class by 1 per cent reduces the propensity to use pesticides by 0.16 per cent. In contrast, an increase in the proportion of establishments in the 1000–10,000 hectare class by 1 per cent increases the propensity to use pesticides by 0.29 per cent. This reflects the concentration of pesticide use among larger farmers who have higher expected gains from risk reduction, reducing yield risks from insects and disease because they use higher levels of fertilizer and more improved seed than smaller farmers do. Among different ownership categories, the effects of individual ownership were found to be negatively associated with pesticide use, while sharecropping contributes positively to pesticide use. A 1 per cent increase in proportion of land under individual ownership decreases the proportion of land with pesticide application by 0.07 per cent, while a 1 per cent increase in the proportion of land under sharecropping corresponds to an increase in the proportion of pesticide-applied land by 0.10 per cent. Rental arrangements were found to be insignificant. The higher use by sharecroppers probably indicates the pressure of the landowners to reduce their risks.

Among the various land-use patterns, both permanent and temporary crops and livestock raising are significantly and positively associated with pesticide use. The association with conservation tillage is also highly significant and positive. This most likely reflects the direct relationship between conservation tillage and herbicide use, at least in the initial phase of adoption of conservation tillage and before full adoption of the complete 'package', e.g., 1. no turning over the soil (no-till), 2. direct planting, 3. crop rotation, and 4. permanent soil cover.[17] Our results also suggest strong

[15] Results are reported for 4,411 municipalities, since 497 lacked information on either income or education. Tobit estimates yielded similar results as OLS estimates, since the number of municipalities having a value of 0 for PROPUSE was small (153 out of 4,411). In fact, the use of Tobit estimation is debatable here (see, Maddala, 1992: 341–342 for details).

[16] Only the significant variables are presented here. A complete list of variables is available on request.

[17] We acknowledge Christian J. Pieri for clarifying this point.

crop patterns. Positive significant shares of soybeans, sugarcane, tobacco, cotton, and fruits[18] suggest higher pesticide usage on most of the major cash crops for export. This can be explained by the fact that the most

Table 3. *Pattern of propensity to use pesticides (in %)*

Variable	*Meaning*	
Constant		−0.215
		(−3.92)
Income	Median income	3.43E-06
		(6.56)
Income^2	Square of median income	−9.36E-12
		(−3.47)
Educ	Proportion of population with secondary education	0.001
		(2.51)
PEstOwner	Proportion of individual owners	−0.070
		(−2.28)
PEstSharecropper	Proportion of sharecroppers	0.103
		(1.89)
Prop10–100	Proportion of farm size: 10–100 ha	−0.158
		(−5.50)
Prop1000–10000	Proportion of farm size: 1000–10000 ha	0.291
		(3.24)
PropUseCT	Proportion of farms with conservation tillage	0.282
		(15.21)
PropCrop-Live	Proportion of farms with crop–livestock land use	0.239
		(5.44)
Cocoa		0.063
		(1.31)
Coffee		−0.204
		(−4.24)
Cotton		1.038
		(15.30)
Soya		0.793
		(16.03)
Sugar		0.494
		(10.54)
Tobacco		0.884
		(12.15)
Fruits		0.355
		(4.06)
Vegetables		0.262
		(5.31)
Grains		0.158
		(3.47)
Adjusted R^2		0.50
N		4411
F- Statistic (Prob)		247.21 (0.00)

Note: Robust standard errors are used and t-statistics are in parentheses. All coefficients are significant at at least 10% .

[18] Soybeans, coffee, sugarcane, tobacco, cocoa, cotton, and fruits jointly accounted for 25 per cent of total agricultural exports during 1997.

profitable crops benefit from the highest input use. Export crops happen to be in general the most profitable crops in Brazil. Some of these crops (e.g., fruits) are subject to cosmetic quality standards requiring use of insecticides. Controls for income and income squared clearly indicate that high-income municipalities have higher propensity to use pesticides, and the proportion of agricultural land with pesticide use is increasing at a decreasing rate with income. Areas with higher incomes may be approaching the peak of marginal gains to pesticide use, where the benefits (e.g., productivity) to additional use are small in comparison to the costs. Interestingly, increases in education also lead to a higher propensity to use pesticides. Contrary to our *a priori* expectations, it may be that in areas where literacy is high, there are active campaigns to promote the use of pesticides.

In sum, these results indicate higher incidence of pesticide use in municipalities with high income, higher levels of education, large-size farms, predominance of export crops and vegetables, and high prevalence of sharecropping. These results have several implications. First, any policy designed to effectively alter pesticide use should consider these demographics as key variables of interest. In particular, since the type and value of crops (e.g. cotton) matter a great deal, policies targeted toward a few influential crops may be important in altering pesticide use.[19] Second, as increased pesticide use brings about increased agricultural production and incidence on human health (see section 4), appropriate policy must address this tradeoff.

Third, although these cross-section results do not directly address the inherently dynamic issue of the impact of trade liberalization on pesticide use, they nevertheless offer important useful insights. Indeed, a case can be made that pesticide-related information in the 1996 municipality census is the resulting impact of trade liberalization in the 1990s. This is reinforced by Baumann, Rivero, and Zavattiero's (1998: 1971) remark according to which trade liberalization reached its peak in the first quarter of 1995. That is, the 1996 census implicitly contains the net agricultural trade liberalization effect. Agricultural trade liberalization has tended to favor larger farms, which in turn are big users of pesticides, and are associated with better educated farmers with higher incomes.

Fourth, if these results can be extrapolated to time series, then they indicate that the continuation of current trends toward commercialization, industrialization and globalization of agriculture, consolidation of land holdings, and movement from family farming will further encourage pesticide use in Brazil.

Pesticide use: further observations

The most profitable crops benefit from the highest input use, irrespective of the source of demand (domestic or foreign). In Brazil, the most profitable crops are export cash crops. Put differently, export crops benefit

[19] If prices were available we would have computed optimal pesticide use under different scenarios. This would have facilitated a quantification of pesticide overuse if it existed.

from more pesticide use than other crops since export crops are by and large associated with large mechanized farms. Moreover, a large number of export crops (e.g., fruits), as well as non-traditionally traded crops, are subject to cosmetic quality standards that have resulted in increases in pesticide use (Thrupp, Bergeron, and Waters, 1995). In that connection, Pingali correctly indicated that, 'Pesticide application in high value crops is related to consumer demand for aesthetically appealing agricultural products. Since these high-value agricultural products enjoy a substantial premium for unblemished physical appearance, risk-adverse farmers tend to apply pesticides, beyond the technical optimum, in order to capture this price differential' (1999: 16). Brazil has a comparative advantage in quite a number of these export crops.

Pesticide use increases have been less in non-export crops (i.e., cassava and beans) generally produced by small landholders with limited education, capital, and access to pesticides. Exceptions to this observation are crops such as corn and vegetables that are generally produced on large farms that benefit more from pesticide use.

Pesticide use varies by category. The preponderance of herbicide use since the early 1980s arose from: 1 the shift toward large, monoculture plantations; 2 the expansion of plantation crops such as soybeans, cotton, and sugar cane (Bellotti, Cardona, and Lapointe, 1990); and 3 the rapid urbanization that led to a shortage of rural labour, inducing substitution of weed controls for hand weeding. The concentration of pesticide use among soybeans producers in the south and sugar producers in the northeast may indicate the degree of difficulty these large farmers have in getting sufficient labour for timely weeding. Insecticides and fungicides reduce yield variance. Increased use of inorganic fertilizers and improved seeds thus increase the returns to yield risk reduction by increasing expected returns.

Policies encouraging pesticide use include subsidies, price controls, agricultural credit and crop insurance tied to pesticide use, erroneous government pest management policies, pro-chemical bias of information provided to farmers, and inadequate curricula of agricultural education and extension (Farah, 1994). Some of these factors are price related and others not. Price-related factors (e.g., pesticide subsidies) effectively lower pesticide prices, leading to pesticide overuse (Repetto, 1985).[20] In studying the impact of prices on farmer behavior in Brazil, Lutz (1992), citing evidence from Lopez (1977), concludes that small farms would respond less than larger farms, and that the larger farms would dramatically expand production, land and labor use, and input use, with negative consequences overall.

On the supply side of pesticide use are the input industries. The requirements imposed by contracts between firms (faced with quality requirements and processing, and transport capacity limits that put a premium on steady throughput volumes) foster increased pesticide use. Growth in the agro-processing industry also encourages the development of upstream farm input companies, perhaps including pesticide producing companies. Prior to trade liberalization the Brazilian pesticide industry benefited from 'several subsidies such as generous tax and credit

[20] Farah (1994) gives more details on this topic.

incentives, cheap labor and few pollution control requirements' (Farah, 1994: 31) intended to reduce domestic pesticide prices and develop local industry. This was primarily due to the creation of the National Pesticide Program (PNDA – Programa Nacional de Defensivos Agrícolas), in 1975. The program was decisive for the establishment of the pesticide industry, whose main goal was to reduce the volume of imports of formulated pesticides, improve domestic production, and thus reduce domestic pesticide prices (Futino and Silveira, 1991). Fiscal incentives played an important role in promoting the domestic production of these products. Imports of active ingredients were exempt of tariffs during this period and, as a result, many multinational agrochemical companies opened manufacturing facilities in Brazil, producing nearly 50 pesticides.[21] Imports of formulated products decreased by 80 per cent from 1975 to 1980. By 1984, approximately 74 per cent of pesticides and 64 per cent of insecticides used were produced in Brazil (Bellotti, Cardona, and Lapointe, 1990: 196). With the advent of trade liberalization (e.g., reduction of import tariffs and phasing out of non-tariff barriers), companies ceased local production of pesticides because of competition from cheaper imported chemical pesticides.

5. Social costs of pesticide use

It was noted in the previous section that the decision to use pesticides is a result of equating private benefits and private costs. However, since private costs do not internalize the external costs of pesticide use, this does not reflect the true social costs of use. The divergence between the private and social costs of pesticide use generates important inefficiencies. This section looks at some elements of social costs that may be taken into account in the private calculus of pesticide use with policy implications.

Social costs are private costs plus external costs (e.g., intoxication cost and soil degradation cost). Many pesticides used in Brazil have been classified by the World Health Organization as extremely toxic.[22] As a consequence, health risks due to pesticide exposure are evident among Brazilian farmers (see table 4). While the country as a whole does not monitor the health impact of pesticides,[23] regional poison control centers do keep records (Dinham, 1993).[24] Based on the World Health

[21] Although quite a number of domestic companies entered the market, Brazilian pesticide production is still dominated by multinational companies.

[22] Of the herbicides, insecticides, fungicides, and acaricides regulated by the Brazilian government, nearly 48 per cent are classified as being Class Ia (extremely hazardous) or Ib (highly hazardous) by the World Health Organization (WINFIT-2000, 1998).

[23] Unfortunately most pesticide-related poisonings are not registered since they do not receive medical attention. Moreover, doctors are not trained to recognize pesticide-poisoning symptoms, commonly mistaking symptoms for food poisoning or other illnesses.

[24] Of the states who do track, in 1993 over 10,223 general cases of serious poisoning were registered in the North East of Brazil (Augusto and Araújo, 1999). According to the Health Secretariat of Paraná, 9,540 cases of pesticide poisoning were reported from 1986 to 1997, of which 919 cases resulted in death (Cordeiro, Marochi, and Tardin, 1998).

Table 4. *Regional registrations of pesticide intoxication, 1993–1998*

Region/State	*Year*					
	1993	*1994*	*1995*	*1996*	*1997*	*1998*
North	–	–	–	**50**	**100**	**3,500**
Amapá	–	–	–	50	100	150
Pará	–	–	–	–	–	3,350
Northeast	**15,350**	**19,050**	**26,800**	**32,800**	**30,800**	**35,250**
Ceará	7,200	10,350	14,950	20,000	21,150	22,750
Rio Grande do Norte	1,050	550	–	250	–	400
Paraíba	400	450	850	800	1,250	2,100
Pernambuco	500	400	400	450	1,300	1,900
Bahia	6,200	7,300	10,600	11,300	7,100	8,100
Southeast	**77,250**	**130,800**	**131,450**	**117,800**	**145,200**	**129,800**
Minas Gerais	4,750	5,150	7,000	9,950	9,350	11,150
Espírito Santo	6,100	4,800	–	–	13,750	7,400
Rio de Janeiro	8,400	5,100	14,000	14,850	15,250	9,300
São Paulo	58,000	115,750	110,450	93,000	106,850	101,950
South	**59,700**	**64,100**	**73,700**	**76,750**	**82,400**	**77,850**
Paraná	16,100	15,650	15,150	14,050	16,150	15,800
Santa Catarina	11,650	16,250	19,600	21,250	21,400	23,350
Rio Grande do Sul	31,950	32,200	38,950	41,450	44,850	38,700
Central West	**18,600**	**19,700**	**13,600**	**13,800**	**15,200**	**17,000**
Mato Grosso do Sul	10,400	14,650	8,050	7,850	8,150	6,750
Mato Grosso	3,650	3,100	2,000	2,600	2,700	3,050
Goiás	4,550	1,950	3,550	3,350	4,350	7,200
Total	**170,900**	**233,650**	**245,550**	**241,200**	**273,700**	**263,400**

Note: The numbers above were calculated using a formula by the World Health Organization, where reported numbers are multiplied by 50.
Source: SINITOX (1999).

Organization's estimate that there are 50 cases of poisoning for every case reported and registered, the Brazilian Ministry of Health estimates 263, 400 cases of intoxication from pesticide exposure as of 1998 (Lins, 1996; PANNA, 1997). On the cost side, approximately US$47 million is spent annually for treating pesticide poisonings in Brazil (Lins, 1996).

Taking a closer look at table 4, one can see that the major agricultural areas of the southeast and the south account for nearly 50 per cent and 30 per cent of total registered intoxication, respectively. In these two regions, the average growth rate of intoxication over the period has been 32 per cent, with the northeast experiencing the highest growth rate of 56 per cent. The states of Paraná, Mato Grosso do Sul, Santa Catarina, São Paulo, Goiãs, Mato Grosso, and Rio Grande do Sul cumulatively accounted for 81 per cent of all pesticide use during 1997 (SINDAG, 1997). These heavy-use areas accounted for 75 per cent of total reported intoxication cases.

In addition to the human health impact, environmental degradation from pesticide use is also apparent in Brazil. For example, using gas and liquid chromatography techniques, it has been found that organophosphate and pyrethroid residues are at levels above World Health Organization standards in 35.3 per cent of water samples collected from irrigation and drinking water in Brazil (Inoue, 1993). Technical analysis has revealed the contamination of soils resulting from inappropriate management and application of pesticides in irrigated areas of Bahia (*A Tarde*, 1997). PAN Brazil and the Union of Rural workers of Vargeao in February 1994 reported the poisoning of millions of birds in furadan- (carbofuran)[25] treated wheat fields in the Southern Brazilian state of Santa Catarina (PANNA, 1994).

In order to assess the environmental risks associated with the most extensively used pesticides in Brazil, we tabulated the underlying active ingredients of each pesticide typically used to treat soybeans, sugarcane, tobacco, cotton and fruits.[26] As expected, the list of active ingredients revealed a wide variation in relative toxicity. In table 5, we have constructed indicators of toxicity, using methods similar to Higley and Wintersteen (1992), where active ingredients for all pesticides were categorized into three groups: high, moderate, and low risk according to their lethal dose and concentration impact upon the receiving environment.

Alarmingly, results indicate that 46 per cent of the active ingredients currently used in Brazil (and primarily associated with export crops) pose medium/high risk to humans. For aquatic organisms, medium/high risk active ingredients total approximately 95 per cent. For mammals and birds, medium/high risk active ingredients are 47 per cent and 41 per cent, respectively.

This evidence emphasizes the existence of serious environmental costs as well as health hazards associated with pesticide use in Brazil. These are basically the result of pesticide overuse or misuse (indiscriminate use) which in turn reflects the divergence between private costs and social costs. Farmers do not bear the full social costs of pesticide use, thereby raising the possibility of government intervention to correct the situation.

Table 5. *Proportion of active ingredients belonging to each toxicity category across the receiving environment*

Environmental category	*High risk*	*Medium risk*	*Low risk*	*Total*
Humans – acute toxicity	13	33	54	100
(e.g., rats)	Oral $LD_{50} < 50$	Oral LD_{50} 50–500	Oral $LD_{50} > 500$	
Mammals	17	30	52	100
(e.g., rats, rabbits, mice)	Oral $LD_{50} < 50$	Oral LD_{50} 50–500	Oral $LD_{50} > 500$	
Birds	21	20	59	100
(e.g., quail, pheasants)	Oral $LD_{50} < 50$	Oral LD_{50} 50–500	Oral $LD_{50} > 500$	
Aquatic organisms	77	18	5	100
(e.g., flathead minnows, trout)	$LC_{50} < 50$ [1]	LC_{50} 50–500	$LD_{50} > 500$	

Note: Numbers may not necessarily add to 100 due to rounding.
[1] LC_{50} in mg/liter (=ppm); LD_{50} in mg/kg.
Sources: World Bank (1993), Tomlin (1994).

[25] Furadan is the trade name for granulated carbofuran (a long-lasting pesticide) produced in Brazil. It is applied to seeds as a safeguard against pests that may or may not occur later in the growing season.

[26] Following information contained in World Bank (1993) and Tomlin (1994).

At the very least, policies fostering pesticide overuse (see above) should be re-examined for their potential contribution to external social costs. In particular, pesticide subsidies, once a permanent reality in Brazil, must end. However, the abandonment of these subsidies does not necessarily translate into a complete solution to the problem of pesticide overuse or misuse. As Runge (1992) and others point out, the effectiveness of well-constructed agricultural trade policy in addressing environmental concerns will only go so far without complementary environmental policies which address hazardous conditions more directly. In that connection, as pesticide use has been mainly concentrated on a few crops, mainly export crops, attention should be given to policy which affects the decisions underlying the production of these crops. Economic incentives, such as pesticide taxes (e.g., pollution taxes), if successfully devised may encourage the adoption of alternatives, such as integrated pest management (IPM) (Kahn, 1998: 452), which relies on environmental, genetic, chemical, and cultural controls to deal with pests (Chiras, 1991: 421). Enforcement of existing regulations (e.g., bans on some pesticides and use of low conservation tillage) and economic incentives may help induce farmers to adopt less pesticide-intensive farming methods. Whatever option is chosen, participatory farmer education is key to any successful program of pesticide use abatement.

6. Implications and conclusions

Empirical evidence on changes in pesticide use brought about by agricultural trade liberalization in developing countries is rather thin. In this paper, we have analyzed pesticide use in Brazil in the 1990s, a decade characterized by trade liberalization.

Agricultural trade liberalization has a contributed to an increase in pesticide use in the 1990s, a period that witnessed a doubling of use. Evidence also suggests that there are serious human health issues and environmental damage associated with pesticides.

Our cross-section regression results suggest widespread pesticide use in the major agricultural regions in the center south of Brazil. Cumulatively, the states of Paraná, Mato Grosso do Sul, Santa Catarina, São Paulo, Goiãs, Mato Grosso and Rio Grande do Sul accounted for 81 per cent of all pesticide use in Brazil during 1997. We find a higher incidence of pesticide use in the municipalities characterized by high income, higher levels of education attainment, large-size farms, and with a high prevalence of sharecropping. If cross-section results can be extrapolated to time series, our results indicate that the continuation of current trends towards the commercialization of agriculture, consolidation of land holdings, and movement from family farming will further encourage pesticide use in Brazil.

Our results also confirm earlier findings (Bellotti, Cardona, and Lapointe, 1990; World Bank, 1993) that pesticide use in Brazil is heavily skewed towards a few cash crops for export. Crops such as soybeans, sugarcane, cotton, fruits, and tobacco are the major recipients of pesticides (receiving 60 per cent of total application during 1997). This suggests policies targeted toward a few crops – strict enforcement of existing regulations, farmer education and training, integrated pest management programs, and research on alternative pest control methods – may have measurable beneficial effects for sustainable development in Brazil. While targeted intervention emerges as a promising possibility from our analysis, clearly further research on the feasibility, cost–benefit, and responsiveness of farmers to various alternatives is necessary to design an effective pesticide use reduction strategy.

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