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Agricultural Trade, Development and Toxic Risk

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Summary. — This paper uses a large database of laboratory test results to investigate the sources of international variation in pesticide residues on food products. We specify and estimate a model that incorporates contamination effects attributable to product pest sensitivity, pesticide toxicity levels and characteristics of the producing country. Among the latter, our model tests for the effects of income, education and openness to trade. We find large and highly significant "generic" differences in contamination of food products, reflecting pesticide applications that vary with pest sensitivity. Controlling for these differences, we find strong effects for income and education. Pesticide residues on agricultural products fall sharply as income increases, but rise significantly with education. Our model attributes the latter effect to the choice of more capital-, skill- and pesticide-intensive technologies in better-educated societies. We find no significant impact for openness to trade. Our results suggest that workers and consumers in low-income societies have far higher exposure to toxic pesticides than their counterparts in high-income societies, but that consumers in the latter experience significant increases in toxic exposure risk as agricultural trade with developing countries expands. The paper concludes with a discussion of appropriate instruments for resolving a potentially serious trade-environment conflict on this front.

Key words — pesticide residues, pesticide risks, food consumption, agricultural trade, crosscountry

1. INTRODUCTION

Liberalization of trade and investment has significantly expanded exports of agricultural products from developing countries. According to Thrupp, Bergeron, and Waters (1995), nontraditional agricultural exports grew by 17% annually from Central America during 1985–92, and by 48% annually from South America (excluding Brazil). This growth has generated substantial employment benefits for unskilled workers. In Colombia, for example, the growth of the flower export industry has created about 80,000 jobs, 80% of which are held by women (Thrupp *et al.*, 1995). Unfortunately, producers of many export crops also use fertilizers and pesticides intensively (Dasgupta, Mamingi, & Meisner, 2001b; Maxwell & Fernando, 1989). The results have included significant increases in polluting runoff, crop contamination and health damage from workers' exposure to toxic pesticides (Langman, 1999; Williams & Shumway, 2000). Several micro-studies of health costs and productivity losses in Asia and Latin America have suggested excessive pesticide use by rural farmers (Antle & Pingali, 1994; Pingali, Marquez, & Palis, 1994; Crissman, Cole, & Carpio, 1994; Antle, Cole, & Crissman, 1998; Dung & Dung, 1999). Fragmentary international evidence also indicates that pesticide poisoning is underreported in clinical data. In Ecuador, for example, field surveys show that only 9% of pesticide poisoning cases result in clinical care (Crissman *et al.*, 1994). Jeyaratnam (1990) estimates that three million pesticide poisonings occur annually in developing countries.

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* The views expressed here are the authors' and do not reflect those of the World Bank, its Executive Directors, or the countries they represent. Final revision accepted: 10 April 2002.

Such evidence is cited by critics of trade liberalization who argue that free trade with low-income countries exploits agricultural "pollution havens," where low-cost production with unregulated pesticide use increases toxic exposure for agricultural workers, as well as consumers in countries that import their contaminated produce (Sagaris, 1999; Rauber, 1997). From a theoretical perspective, the critics have a plausible case. Recent studies suggest that economic development strengthens pollution regulation by increasing communities' sensitivity to environmental damage, as well as their willingness and ability to do something about it (Dasgupta & Wheeler, 1996; Dasgupta, Mody, Roy, & Wheeler, 2001a; Pargal & Wheeler, 1996; Dean, 1999). Pollution control uses scarce resources, so polluting activities in high-income economies have higher regulatory costs than their counterparts in developing countries (Jaffe, Peterson, Portney, & Stavins, 1995; Mani & Wheeler, 1999). This creates a source of potential "comparative advantage" for the latter that might induce some highly polluting agricultural activities to relocate under free trade. Empirically, the question turns on whether differences in regulatory costs outweigh other locational considerations, and whether internationally mobile activities actually pollute more in developing countries.

Extensive research has examined the pollution havens hypothesis for industrial activity. The results suggest that pollution control costs are not major determinants of relocation (Eskeland & Harrison, 1997; Albrecht, 1998; Levinson, 1997; Van Beers & Van den Bergh, 1997; Tobey, 1990; Janicke, Binder, & Monch, 1997), and that most OECD-based multinationals maintain near-uniform environmental standards in their plants (Dowell, Hart, & Yeung, 2000). The evidence also suggests that pollution havens can emerge in extreme cases (Xing & Kolstad, 1995). During the 1970s, for example, environmental regulation tightened dramatically in the OECD economies with no countervailing change in developing countries. The regulatory cost differential was apparently sufficient to generate a surge in production and exports of pollution-intensive products from developing countries. Since then, however, regulatory changes in the latter have narrowed the gap and stopped the net migration of polluting industries (Mani & Wheeler, 1999). In the present, relatively stable situation, developing-country industrial imports from high-income economies remain more concentrated in pollution-intensive sectors than do their exports to those economies (Mani & Wheeler, 1999; Albrecht, 1998). But, weaker regulation also ensures that the pollution-intensity of production activities is generally higher in developing countries (Mani, Hettige, & Wheeler, 2000).

Tests of the pollution havens hypothesis for agriculture have been rare because data scarcity has hampered systematic research. Two recent studies suggest that NAFTA has not created significant pollution haven effects in Mexico. In a CGE-based simulation, Beghin, Dessus, Roland-Holst, and van der Mensbrugghe (1997) use sectoral pollution intensity estimates from Dessus, Roland-Holst, and van der Mensbrugghe (1994) to assess the environmental impact of sectoral output changes in Mexico under trade liberalization. Overall, they find no specialization in dirty agricultural activities and a pattern of output contraction in some sectors that actually eases pressure on the environment. Using an alternative approach, Williams and Shumway (2000) find significant expansion in agricultural output, fertilizer use and associated runoff pollution under trade liberalization. But, their price increase projections for pesticides, combined with high estimated price elasticities, suggest a significant decline in pesticide exposure during the period of expansion.

These studies have provided important insights, but their generality is limited by their country focus and their reliance on "generic" sectoral pollution intensities because broader international datasets have not been available. Additional evidence may be particularly important in the case of pesticide use, because of its potentially widespread health impacts. As the previously cited studies suggest, excessive pesticide applications have imposed substantial health costs and productivity losses on farmers in developing countries. In addition, health risks are spread through trade in products contaminated by pesticide residues. Within developing countries, where food quality regulation is generally weak, these residues may be high enough to pose serious toxic risks.

The risks may also be significant for consumers in high-income importing countries, for several reasons. Food quality regulations in most OECD countries specify maximum tolerable residues for toxic pesticides, and border inspectors are empowered to reject shipments that exceed the standards. Monitoring and enforcement of such regulations are however always imperfect. Some analysts have also suggested that frequent consumption of products with allowable toxic residues can easily result in cumulative exposure that exceeds established reference doses (Groth, Benbrook, & Lutz, 1999). In addition, the relationship between reference doses and overall risk remains uncertain. These doses are typically established through single-chemical exposure of adult laboratory animals. By contrast, public health concerns focus on children's consumption of foods that contain residues from multiple pesticides. Possible interactive effects from multiple exposures remain largely unexplored. Finally, most pesticides are nerve poisons, and current scientific knowledge is not sufficient to establish exposure levels that are free of developmental impacts on children and fetuses (Groth *et al.*, 1999). At the current state of knowledge, prudence would suggest minimization of exposure to toxic residues, particularly for vulnerable groups such as young children and pregnant women.

The critical empirical question in this context is whether pesticide applications produce significantly higher contamination of agricultural produce in developing countries. In this paper, we address the issue with newly available sampling information from the pesticide data program (PDP) of the US Department of Agriculture. The PDP database provides information from over 27,000 samples of imported and US-produced food products during 1994–97. For each sample, it identifies the product, sampling date, country of origin and degree of contamination by a large number of toxic chemicals found in pesticides. The US Environmental Protection Agency provides complementary estimates of the acute and chronic exposure risks associated with each chemical. For econometric analysis, we have combined the toxic residue and risk data with information on source-country characteristics from the World Bank's database.

The remainder of the paper is organized as follows. Section 2 introduces the PDP dataset and discusses the measures of toxic residues and risk that are the focus of our analysis. In Section 3, we specify and estimate an econometric model that relates toxic residues to product pest sensitivity, pesticide toxicity, and source-country characteristics that include income, education and openness to trade. Section 4 explores the implications of our results in a set of simulation experiments, while Section 5 concludes the paper with a discussion of policy options.

2. THE DATABASE

Since 1991, the US Department of Agriculture's PDP has systematically tested foods sold in the US for pesticide residues. Publicly available PDP data for 1994–97 summarize results from 27,000 samples for 27 foods (Table 1). The tested foods were produced in 16 countries whose 1997 GNP per capita varied from \$700 to \$29,000 (Table 2). Each sample contains about five pounds of produce, and the USDA's test protocol requires testing foods "as eaten" (i.e., after pre-consumption washing, peeling or cooking). The PDP analysis reports residues of 80 chemical pesticides that are identified in Table 3. For these compounds, the US Environmental Protection Agency has established standard measures of acute and chronic toxicity that are based on controlled exposure analyses. In the case of acute toxicity (risk from a single exposure), the standard measure is the dose that kills half of an exposed group of test animals (LD_{50}). Table 3 provides LD_{50} measures for the 80 chemicals, along with a transformation ($100 \times 1/LD_{50}$) that yields an index of relative toxicity (Groth *et al.*, 1999). The distribution of index values is exponential, varying by a factor >5,000 from maximum to

Table 1. *Foods in the estimation sample*

Apple juice
Apples
Bananas
Broccoli
Carrots
Celery
Grapes
Green beans, fresh
Green beans, canned/frozen
Lettuce
Milk
Orange juice
Oranges
Peaches, fresh
Peaches, canned
Pears
Potatoes
Soybeans
Spinach, fresh
Spinach, canned
Sweet corn, canned/frozen
Sweet peas, canned/frozen
Sweet potatoes
Tomatoes
Wheat
Winter squash, fresh
Winter squash, frozen

Table 2. *Country sample used for estimation*

Country	GNP per capita, 1997
Honduras	700
Guatemala	1500
Ecuador	1590
Colombia	2280
Costa Rica	2640
Panama	3080
South Africa	3400
Mexico	3680
Hungary	4430
Brazil	4720
Chile	5020
Argentina	8570
New Zealand	16,480
Canada	19,290
Germany	28,260
US	28,740

Source: World Bank (various issues), World Development Indicators.

minimum. For chronic toxicity (risk from repeated exposure), a standard conservative measure is the "reference dose"—typically 1% of the highest dose that has no observed adverse effect on test animals. Reference doses also vary by three orders of magnitude in the sample, with maximum index values 8,000 times minimum values.

For the econometric analysis reported in this paper, we have constructed a panel dataset that includes the PDP data, the USEPA toxic risk indices, and World Bank data for variables related to development and trade. Our PDP estimates are sample averages by toxic chemical, product, country and year.

3. THE MODEL

For product *i*, pesticide *j* and country *k*, we specify pesticide residue per unit weight as

$$P_{ijk} = A_{ijk} - R_{ijk} \tag{1}$$

where P is the measured residue (mg/kg), A is the residue from field application (mg/kg), and R is the residue removal before testing (mg/kg).

The field application volume of pesticides is determined by several factors. First, crops differ substantially in their vulnerability to insect pests; at constant toxicity per unit of application, more pesticide will be applied to more vulnerable crops. In the econometric analysis, we control for this effect using crop-specific dummy variables. Second, field surveys have suggested that applicators are aware of the risks associated with use of highly toxic pesticides (Crissman *et al.*, 1994). Since manufacturers' labels indicate the degree of pesticide toxicity, we expect application volumes to be negatively associated with toxicity (*ceteris paribus*). We also posit that three characteristics of producing countries may affect application volume: openness to trade, worker education, and regulatory strictness

$$\begin{gathered} A_{ijk} = f(c_i, r_j, o_k, e_k, s_k) \\ f'(r), f'(s) < 0 \\ f'(o) \overset{>}{\underset{<}{-}} 0, \quad \frac{\partial^2 f}{\partial o \partial y} \overset{<}{\underset{>}{-}} 0, \quad f'(e) \overset{>}{\underset{<}{-}} 0 \end{gathered} \tag{2}$$

where c is a crop-specific pest sensitivity parameter, r is an index of exposure risk, o is the degree of openness to trade, e is the worker education and s is the regulatory strictness.

We are agnostic about the role of openness to trade, because it may have countervailing effects. Openness may reduce pesticide applications for several reasons. First, it increases export orientation and facilitates access to new technology and information. Second, pesticide application decisions by export-oriented farmers should be affected by health and safety standards in high-income importing countries. In addition, greater openness in low-income countries should improve access to less pesticide-intensive technologies whose implementation relies on imported equipment, supplies and skills. On the other hand, openness may increase pesticide use because farmers in open economies have lower-cost access to imported pesticides, and because export-oriented farmers may increase applications to reduce physical blemishes from insect damage. The sign on openness in Eq. (2) is therefore ambiguous. If there is a significant net impact, however, we expect it to be greatest in the poorest economies.

Pesticide applications should be negatively related to exposure risk for farmers, along with the strictness of local health and safety regulation. Worker education may have countervailing effects. The production complementary of pesticides, capital and skilled labor should create a positive association between education and pesticide applications (Dasgupta *et al.*, 2001b). On the other hand, more educated workers may apply pesticides more cautiously because they are more aware of exposure risk. More educated workers may also adopt better protective mea-

Table 3. *Acute toxicity of pesticides detected by the PDP program, 1994–97*

Pesticide	LD_{50} (mg/kg)	Toxicity index ($100 \times 1/LD_{50}$)
Aldicarb sulfoxide	0.93	107.50
Aldicarb	0.93	107.50
Phorate sulfone	2.00	50.00
Disulfoton sulfone	2.60	38.46
Mevinphos	4.00	25.00
Oxamyl	6.00	16.67
Phosphamidon	7.00	14.29
Carbofuran	8.00	12.50
Carbofuran-3 OH	8.00	12.50
Parathion-ethyl	14.00	7.14
Parathion-methyl	14.00	7.14
Fenamiphos	15.00	6.67
Fenamiphos sulfoxide	15.00	6.67
Azinphos-methyl	16.00	6.25
Methomyl	17.00	5.88
Formetanate HCL	21.00	4.76
Methidathion	25.00	4.00
Aldoxycarb	27.00	3.70
Demeton-*S*-sulfone	30.00	3.33
Methamidophos	30.00	3.33
Dieldrin	37.00	2.70
Omethoate	50.00	2.00
Bifenthrin	55.00	1.82
Dichlorvos (DDVP)	56.00	1.79
Lamba-cyhalothrin	56.00	1.79
Fenpropathrin	66.00	1.52
Esfenvalerate	67.00	1.49
Endosulfan I	80.00	1.25
Endosulfan II	80.00	1.25
Endosulfan sulfate	80.00	1.25
Cypermethrin	86.00	1.16
Lindane	88.00	1.14
DDD (TDE)	113.00	0.88
DDE	113.00	0.88
DDT	113.00	0.88
Phosalone	120.00	0.83
Chlorpyrifos	135.00	0.74
Dimethoate	150.00	0.67
Ethion	208.00	0.48
Phosmet	230.00	0.43
4-Hydroxydiphenylamine (DPA)	300.00	0.33
Carbaryl	300.00	0.33
Diazinon	300.00	0.33
Diphenylamine (DPA)	300.00	0.33
Imazalil	320.00	0.31
2,4-D	375.00	0.27
Chlordane	460.00	0.22
Fenvalerate	450.00	0.22
Permethrin	500.00	0.20
Diclofop methyl	565.00	0.18
Triadimefon	602.00	0.17
Metalaxyl	670.00	0.15
Dicofol PP	690.00	0.14
Acephate	945.00	0.11
Myclobutanil	1600.00	0.06
Quintozene (PCNB)	1700.00	0.06
Atrazine	2000.00	0.05
Malathion	2100.00	0.05
Propargite	2200.00	0.05

Continued next page

Table 3—*continued*

Pesticide	LD_{50} (mg/kg)	Toxicity index ($100 \times 1/LD_{50}$)
Fenbutatin oxide	2630.00	0.04
o-Phenylphenol	2700.00	0.04
Pentachloroaniline (PCA)	2420.00	0.04
Chlorpyrifos-methyl	3000.00	0.03
Dicloran	4000.00	0.03
Iprodione	3500.00	0.03
Linuron	4000.00	0.03
Thiabendazole	3330.00	0.03
Chlorpropham	3800.00	0.03
Benomyl	5000.00	0.02
Captan	5000.00	0.02
Chlorothalonil	5000.00	0.02
DCPA	5000.00	0.02
Hexachlorobenzene	5000.00	0.02
Methoxychlor	5000.00	0.02
Methoxychlor PP	5000.00	0.02
Piperonyl butoxide	5000.00	0.02
Simazine	5000.00	0.02
Tecnazine	5000.00	0.02
Trifluralin	5000.00	0.02
Vinclozolin	5000.00	0.02

Source: Groth *et al.* (1999).

sures when applying pesticides, but this will limit their own exposure rather than the volume of pesticide that is applied.

Removal of some pesticide residue may occur after harvesting, at local markets, and before shipment to international markets. We posit that the degree of removal is determined by product-specific characteristics (e.g., apples may be easier to clean than broccoli), pesticide toxicity, openness, and strictness of regulation.

$$\begin{aligned}
&R_{ijk} = f(c_i, r_j, o_k, s_k)\\
&f'(r), f'(o), f'(s) > 0\\
&\frac{\partial^2 f}{\partial o \partial y} < 0
\end{aligned} \tag{3}$$

Controlling for product-specific characteristics, residue removal should increase with pesticide toxicity (to reduce consumers' exposure risk), openness to trade (to satisfy higher quality standards) and strictness of regulation. We posit that the openness effect declines with income, so the greatest effects of openness on removal should be observed in the poorest economies.

The model yields unambiguous predictions about the determinants of pesticide residues only for toxicity and regulatory strictness

$$\begin{aligned}
&P_{ijk} = A_{ijk} - R_{ijk} = f(c_i, r_j, o_k, e_k, s_k)\\
&f'(r), f'(s) < 0\\
&f'(o) \gtreqless 0 \quad \frac{\partial^2 f}{\partial o \partial y} \lesseqgtr 0, \quad f'(e) \gtreqless 0
\end{aligned} \tag{4}$$

Residues should decrease with pesticide toxicity and regulatory strictness in the producing country; the sign on openness is ambiguous. Using income per capita as our proxy for regulatory strictness, we specify the following equation for econometric estimation: [1]

$$\begin{aligned}
\ln P_{ijk} = {}& \beta_0 + \sum_{i=1}^{23} \lambda_i c_i + \beta_1 r_j + \beta_2 \ln o_k\\
&+ \beta_3 \ln o_k \ln y_k + \beta_4 e_k + \beta_5 \ln y_k + \varepsilon_{ijk}
\end{aligned} \tag{5}$$

where P is the pesticide residue for product i, pesticide j and country k, c is a 23-element set of dummy variables for products[3], r is the risk index (0 if chemical is high-risk; 1 if low-risk), o is the trade/GDP (an index of openness), e is the secondary school enrollment ratio and y is the income per capita.

We have drawn our measures of income, trade/GDP and secondary school enrollment from the World Bank's database. The measure of risk is a dummy variable that summarizes the toxicity ratings established by the USEPA.

Pesticide residues are measured in mg/kg for standard samples of approximately five pounds, tested "as consumed."

We have estimated Eq. (5) by random effects, as indicated by a standard Hausman test. The adjusted R^2 indicates that the model explains 22% of the total variation in toxic residues after correcting for degrees-of-freedom. While this is certainly adequate for a large estimation sample, it does suggest that random variation in food sample test results is relatively large. Our parameter estimates are reported in Table 4. The results for openness are not statistically significant, suggesting the presence of countervailing impacts as hypothesized in our discussion of the model. Model 2 excludes the openness terms, with little effect on the other parameter estimates. The most striking result is for income, which has a very strong, significant effect on toxic residues. [2] After controlling for pesticide toxicity, product pest sensitivity and other factors, the estimated elasticity in Model 2 suggests that residues decrease by 2.4% with each 1% increase in income. In the case of education, the results reflect two countervailing factors: caution in application (negative) and technical substitution (positive). The estimated net impact of education is positive and highly significant. [3] The estimated toxicity adjustment factor is also large, highly significant, and in line with our prior expectations: *Ceteris paribus*, applications (and therefore residues) are much lower for pesticides that are rated highly toxic.

Table 4. *Regression results*

Variables	Model 1		Model 2	
	Parameter	t^*	Parameter	t^*
Constant	15.1699	2.807*	11.0474	2.900*
Log income	−2.7707	−4.467*	−2.3712	−6.257*
Openness (trade/GNP)	−17.2451	−1.397		
Log income × openness	1.8942	1.402		
Secondary enrollment ratio	0.0455	2.974*	0.0515	3.898*
Toxic risk factor (0 = high; 1 = low)	1.0223	7.070*	1.0126	7.072*
Products				
Bananas	2.3396	3.021*	2.1130	3.092*
Peaches (fresh)	1.6822	2.884*	1.7813	3.529*
Apples	1.6064	2.537*	1.6878	3.096*
Celery	1.7414	1.887*	1.6651	1.989*
Pears	1.3195	2.214*	1.3863	2.602*
Spinach (fresh)	1.1877	1.992*	1.1667	2.250*
Green beans (fresh)	0.9316	1.476	0.9241	1.669
Grapes	0.7699	1.434	0.8314	1.759
Oranges	0.5305	0.730	0.4742	0.751
Tomatoes	0.2759	0.458	0.3716	0.724
Lettuce	0.3965	0.444	0.3197	0.397
Wheat	0.1636	0.209	0.1730	0.252
Apple juice	0.0452	0.073	0.0380	0.072
Green beans (frozen, canned)	−0.0529	−0.071	−0.0310	−0.048
Orange juice	−0.1807	−0.218	−0.0550	−0.073
Carrots	−0.4313	−0.690	−0.1977	−0.374
Broccoli	−0.1352	−0.155	−0.2279	−0.280
Potatoes	−0.2353	−0.292	−0.2946	−0.416
Peas (fresh)	−0.3082	−0.335	−0.3593	−0.429
Sweet potatoes	−0.6393	−0.844	−0.6163	−0.936
Peas (frozen, canned)	−0.7304	−0.763	−0.7187	−0.817
Milk	−1.1157	−1.024	−1.0899	−1.066
Corn	−1.8591	−1.064	−1.9071	−1.120
Observations	1170			1181
R^2	0.22			0.22

* Indicates rejection of the standard null hypothesis with at least 95% confidence.

In Table 4, we have ordered the product results from highest to lowest residue intensity. Highly sensitive products include bananas, peaches, apples, celery and pears, while corn, peas, potatoes, broccoli and carrots exhibit relatively low sensitivity. [4] In general, our results suggest that fruit consumption carries substantially more toxic risk than vegetable consumption.

4. IMPLICATIONS OF THE RESULTS

To gauge the relative importance of contamination factors, we have developed two sets of simulations from the parameter estimates. The first, portrayed in Table 5, illustrates the effects of product-specific factors, income and education on toxic exposure. The accompanying education table (Table 6) provides typical values from the World Bank database for low, medium and high secondary enrollment at different income levels. For each product, we calculate the exposure risk index in two steps. First, we use the econometric results to estimate the residue intensity for each pesticide found on each product. Then we multiply the estimated intensities by the EPA indices of exposure risk and sum across pesticides. The results in Table 5 show that although large differences are attributable to variations in all three contamination factors, the income effect dominates. It is so strong that consuming the most generically dangerous product (bananas) from the highest-income economy ($30,000 per capita) is safer than consuming the generically safest product (corn) from the lowest-income economy ($700 per capita).

Table 5. *Simulation results*

Income	Secondary education[a]		
	Low	Medium	High
Bananas			
700	18,760	24,270	31,400
2500	920	2570	4300
5000	180	1080	1800
10,000	210	450	1260
30,000	60	90	160
Grapes			
700	5210	6740	8720
2500	250	710	1190
5000	50	300	500
10,000	60	130	350
30,000	20	30	40
Corn			
700	340	440	560
2500	20	50	80
5000	3	20	30
10,000	4	8	20
30,000	1	2	3

[a] Education data from Table 6.

Table 6. *Typical secondary enrollment ratios*

Income	Secondary education		
	Low	Medium	High
700	20	25	30
2500	20	40	50
5000	20	55	65
10,000	55	70	90
30,000	80	90	100

Source: World Bank (various issues), World Development Indicators.

To illustrate the aggregate implications of these differences, our second simulation is a counterfactual experiment in product sourcing. We produce the baseline estimate by using actual US import volumes for our sample products and countries. To estimate product-specific pesticide residues for each country, we multiply their product import volumes by their residue intensities, as predicted by our econometric model. We then sum across products and countries to obtain the total volume of pesticide residuals for each of four toxic risk classes. For comparison, we use the econometric results to predict residues for the same mix and volume of products from US agriculture. Comparative estimates for the most hazardous (class-4) pesticides (Figure 1) provide some insight into the consequences of the current trade pattern for US consumers. For class-4 toxics, import residues were approximately 100% greater than US residues in 1994, and increased to a 500% margin in 1997. For toxics in less hazardous classes, we find differentials as great as 1,000% in some cases. Many source countries in our simulation have comparatively high incomes, so the results would be even more striking if we simulated diversion of all imports to the poorest trading partners.

5. POLICY OPTIONS

In this paper, we have used a new database to estimate the effects of product pest sensitivity, toxicity, income, education and trade policy on toxic residues in agricultural produce. Overall, our estimating equation explains 22% of the

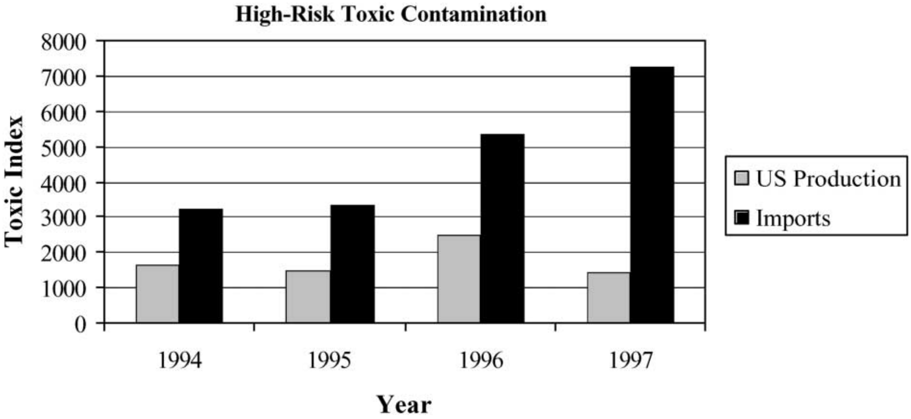

Figure 1. *Hazardous pesticides in US and imported.*

measured variation in toxic residues. A substantial part of the remaining variation may well be due to random variation in product testing results. Our results suggest that environmentalists are correct in claiming that toxic residues are far higher in pest-sensitive products from low-income countries. In addition, we find that differential sensitivity to pests creates large differences in generic toxic risk across products.

Having established the significance of these effects, we conclude by considering the policy implications from the perspective of three affected groups: agricultural workers in low-income countries, consumers in those countries, and consumers in high-income importing countries.

The first question is whether our results have any policy implications at all. Large differences in residue intensities would be meaningless if the highest intensities reflected exposure levels below critical safety thresholds. As we have explained in the introduction, the available scientific evidence does not seem to support this conclusion. Evidence from careful microstudies in a few developing countries also suggests that agricultural workers suffer significant damage from excessive pesticide applications. Our results suggest that consumers in low-income, weakly regulated societies face substantial toxic risks because pest-sensitive local produce is highly contaminated by international standards. Even in high-income importing countries where regulation is stricter and domestic food sources predominate, our evidence suggests that rising imports from low-income economies are increasing toxic exposure risks. An eventual policy response seems likely, particularly in light of the enhanced risk for vulnerable population groups (e.g., children, pregnant women). At the leading edge of the response, highly educated consumers are already increasing their consumption of organically grown produce.

What is to be done? Some Northern environmentalist critics of free trade might simply advocate blocking agricultural imports from low-income, poorly regulated economies. While our results suggest that this would substantially reduce the toxic risk to Northern consumers, it would also raise produce prices in the North while lowering agricultural incomes even further in some of the world's poorest regions. Such a draconian approach would deny market access even to clean producers in the South. In addition, it would do little to reduce toxic exposure for consumers in low-income economies. Since toxic residues fall rapidly with income, free-trade advocates could argue that income growth from trade liberalization will provide the best long-run solution to the problem. In the long run, they are undoubtedly right. But, their critics could justifiably counter that income growth alone will not close the gap for many decades.

Direct regulatory measures in the North could also be employed. The simplest measure would be tightening the current food safety standards to achieve lower exposure risk. This approach would not run afoul of WTO provisions as long as it was applied even-handedly to imports and domestic produce. A more economically efficient, market-based approach to the same problem would impose unit contamination charges that could be adjusted through time until overall exposure targets were met. Only producers who entered an audited self-reporting regime[5] would be allowed to trade in potentially toxic products, and the same charge schedule would be applied to domestic and imported products.

On average, both the standards-based and charge-based schemes would reduce the market share of residue-intensive imports from low-income countries. But, neither would explicitly discriminate against imports (thereby avoiding WTO sanctions), and both would provide strong incentives for clean production in all source countries. The indirect benefits to consumers in low-income countries might well be substantial, since local exporters also produce for the domestic market in many cases. In an extension of the market-based approach, import charge collections by Northern authorities could be rebated to Southern regulatory agencies or extension services to promote faster reduction of pesticide use.

A third possibility would be for governments in low-income countries to set stronger local incentives for reduced use of agricultural pesticides, either through reduction of pesticide subsidies, taxation of pesticide imports, or stricter regulation. Substantial field evidence suggests that the latter approach does not work well. Legal regulations may already be relatively strict, but they are simply not enforced in many cases because local regulators lack the requisite resources.

Reduction of subsidies would certainly help, since microeconometric studies have suggested that pesticides have a fairly high price elasticity of demand. Many countries have made progress on this front, but the overall problem seems to be a long way from solution. As a complement to reduced pesticide subsidies, developing-country governments might also consider support for rural extension programs that instruct farmers in the use of integrated pest management techniques. Finally, higher tariffs on imported pesticides might be quite effective, because low-income countries import many of their pesticides, and enforcement at a few ports would be much less costly than attempts to regulate pesticide applications on widely dispersed farms. Outright import bans may even be appropriate for toxic pesticides that are extremely hazardous and impossible to control by other means. Of course, such policies would represent an explicit movement away from free trade. Local enforcement would also depend on a political judgment that the fiscal, environmental and international trade benefits of such an approach would outweigh the associated loss in agricultural output.

A fourth option might combine targeted use of public information by Northern regulators with assistance for conversion to organic production in the South. Monitoring is much easier in this context, because organic production requires strict adherence to non-chemical regimes. The potential advantage is augmented by the high labor intensity of organic techniques. The critical problems in organic production have to do with information—local-specific information about appropriate cropping and pest-protection measures for farmers, and shipment-specific information for distributors and consumers. The former requires technical assistance, while the latter requires systems of certification that operate at feasible cost. The problem of certification cost would be largely solved if high-income importing countries were willing to test and publicly rate incoming shipments from individual firms. These would not necessarily have to be the original producers, since reputational effects for exporters would feed back to the farmers who sell them produce. Such public ratings would reveal both organic exporters (presumably those whose products have no toxic residues) and the relative contamination of shipments from non-organic exporters. Since the US already maintains a public product impoundment database that specifies exporters by name, it is not difficult to envision specific ratings of exporters by the volume of pesticide residues on their products.[6]

A related approach would use a combination of public information and certification to promote the prospects of developing-country farmers who adhere to organic practices. The current state of the art is exemplified by the Website of the Dominica Banana Marketing Corporation, which has collaborated with trade and government agencies in the United States and United Kingdom.[7] This Website displays the results of a parcel-specific certification process that allows importers of dominican bananas to assess the status of local producers online. Certification is provided by the Corporation, with verification by external agencies. The result is product marketing that is clearly differentiated by chemical input status. Public provision of this information provides a strong incentive for adoption of cleaner production methods.

Ultimately, the choice of strategy in this context depends on assessment of a few basic factors: the health risks associated with exposure to toxic chemicals; the price of pesticides; their productivity; the costs and benefits of switching to organic production; and the monitoring and enforcement costs associated with each regulatory approach. From a risk perspective, agricultural workers in developing countries are undoubtedly suffering the greatest immediate damage from pesticide use. But, the ultimate toll on consumers from recurrent exposure may also be high. Controversy continues about the full carcinogenic, mutagenic and other impacts of long-run consumer exposure, particularly for pesticides that bioaccumulate. Some analysts (e.g., Thornton, 2000) believe that the fully accounted risks are so serious that entire segments of the pesticide industry will ultimately be shut down by fiat. At the current state of knowledge, few serious analysts would be prepared to argue that such risks are negligible.

Pesticide prices are directly observable, and extensive econometric work (as well as farmers' informed choice) has established that the marginal agricultural productivity of pesticides is substantial. At present, however, we know little about the costs and benefits of switching to organic production. Nor has there been much experience with the use of public disclosure and market-based instruments to encourage cleaner production. The time seems ripe for more serious research and policy experimentation in this area, before evident differences in exposure risk provoke more damaging conflicts between environmentalists and advocates of free trade.

NOTES

1. For evidence on the strong relationship between income and regulatory strictness see Dasgupta *et al.* (2001a). In each sample observation, the dummy variable for the product tested is 1. Other product dummies are 0. We exclude dummy variables for four products that are sparsely represented in the sample.

2. "Significance" in this discussion denotes a parameter for which the null hypothesis of zero effect is rejected with at least 95% confidence.

3. The secondary enrollment ratio measures the percentage of young people in the relevant age group who are actually enrolled in secondary school. Potentially, it can vary from 0 to 100. The estimated parameter for secondary education, 0.052, suggests that a unit increase in the percentage enrolled in secondary school is associated with an increase of 0.052 in the logarithm of the toxic residue. In order of magnitude, this is approximately equal to a 5% change in toxic residue.

4. Residues in milk come from residual pesticides in feed grains or direct application of pesticides to pasturage.

5. In such regimes, polluting producers are required to self-report their pollution on a periodic basis, and the reports are randomly audited by third parties. Experience with pollution charges in developing countries suggests that such systems can work, as long as the penalties for misreporting are significant and enforced. A frequent expedient in Latin America is pollution auditing by consulting companies that are blacklisted by regulators if they become corrupt. Since consultants normally depend on business from many clients, experience has shown that they are unlikely to accept payoffs from individual clients unless the risk of discovery is negligible. With a modicum of effort, regulators can keep this risk well above zero. For further discussion, see Wheeler *et al.* (1999).

6. This database can be accessed online at http://www.fda.gov/ora/oasis/ora_oasis_det.html.

7. This website can be accessed online at http://www.dbmc-dm.com/index.html.

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