Essays in Empirical Environmental Economics:
GIS - econometric analysis of Indonesia's fires, Bolivia's deforestation and Mexico's trade with the U.S.

by

Shanti Rabindran Gamper

A.B. Economics & Environmental Science *summa cum laude*, Harvard University, 1994
B.A. Jurisprudence, Oxford University, 1996
M.Sc. Environmental Change & Management, Oxford University, 1999

Submitted to the Department of Economics
In Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Economics

at the
Massachusetts Institute of Technology
June 2001

Signature of Author..
Department of Economics
May 15, 2001

Certified by..
Dora L. Costa
Associate Professor of Economics
Thesis Supervisor

Accepted by ....
Richard Eckaus
Chairman, Departmental Committee on Graduate Studies

ESSAYS IN EMPIRICAL ENVIRONMENTAL ECONOMICS: GIS – ECONOMETRIC ANALYSIS OF INDONESIA'S LAND FIRES, BOLIVIA'S DEFORESTATION AND MEXICO'S TRADE WITH THE U.S.

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Abstract

This thesis examines three environmental issues in developing countries. The first essay examines land fires in Indonesia that inflict severe air pollution-related damage on Southeast Asia annually. Conservative estimates of losses in 1997 alone were US$667 million for Indonesia (0.67% of GDP) and an additional US$12 million for Singapore. Fire incidence on various landholdings is examined using a new author-compiled database on satellite-based fire and rainfall data, land use maps, socioeconomic and geographical information. The essay finds that estates, large-scale industrial plantations that are rapidly expanding in the tropics, raise fire incidence beyond the 'natural' level (the fire incidence on conservation areas serves as a benchmark). In contrast, it finds no evidence that small landholdings, which are often blamed for fires, raise fire incidence. The government's ban on the use of clearance fires, as a result of weak enforcement, did not reduce fire incidence on estates. Alternative policy-levers that could potentially reduce these fires, such as lengthening the estates' leases to improve their property security, are found to be ineffective.

The second essay examines whether education can potentially reduce households' agricultural-related forest clearance by increasing the returns to wage labor. It analyzes a unique survey of 649 indigenous households in protected areas in Bolivia's lowland forests. It finds that an additional year of education among household heads is associated with a reduction of 0.05 hectares or 4.3% of the annual mean household forest clearance, increased returns of 2.6% in wage labor and a 21% increase in days worked in wage labor. Thus the 3-year average increase in education among the youngest cohorts is associated with potentially significant reduction in forest clearance in the study site, though further work is needed to establish causality.

The third essay examines the pollution intensity of the NAFTA-related expansion in US-Mexican trade using new detailed measures of air, water, metal and toxic pollution intensities and injury rates at the 4-digit Standard Industrial Classification level. Based on pollution measures at this resolution, it does not find strong evidence of greater growth in the share of US net imports from Mexico in the more polluting or injurious industries.

Thesis Supervisor: Dora L. Costa
Title: Associate Professor of Economics

Acknowledgement

Dora Costa, my principal advisor, provided solid support throughout my years in graduate school. Steve Pischke and Peter Timmer, my advisors, and William Keller have been similarly generous in their support. James McCarthy, my undergraduate advisor, encouraged me to work on environmental issues. I owe everything to three special people who have nurtured me intellectually and personally through the best and the worst of times. Maureen O'Sullivan and Laurence Pierce have been loving and generous parents. Armin Gamper has been a loving husband and a steadfast friend, cheering me on to seek my own path. I hon Di gern.

In addition, I thank the following persons and organizations for their help.

Indonesia project. Researchers and friends in Indonesia provided invaluable help: Thomas Tomich, Fred Stolle, Carol Colfer, William Sunderlin, Chris Bennett, the Peranginangin family, Hideki Takai, researchers and staff at the Center for International Forestry and the International Center for Research in Agroforestry. Researchers based outside Indonesia also provided generous help: Kamal Bawa, Mark Cochrane, Michael Dove, George Huffman and John Janowiak. MIT faculty and students provided helpful comments: Whitney Newey, David Autor, Abhijit Banerjee, Ester Duflo, Michael Kremer, Sendhil Mullainathan, Nathan Larson, Paras Mehta and Chris Sphor. I also thank Stephan Klasen, David Marks and Christopher Udry for their helpful comments. Data providers permitted my access to data: the Forest Fire Prevention and Management Project - Japan International Cooperation Agency, the Goddard Space Flight Center, the Indonesian Ministry of Forestry and the Indonesian Central Statistics Bureau. The Center for International Forestry, the Conservation, Food and Health Foundation and the Shultz Fund provided funding for this research. The Center for International Agroforestry provided logistical support.

Bolivia project. Tomas Huanca and Josh McDaniel collected the data and field information; Victoria Reyes and Vincent Valdez provided field information and Ricardo Godoy provided data access. Stephan Klasen and Michael Kremer provided helpful comments.

Mexico project. John Baldiserrato, Randy Becker, John Collins and David Wheeler provided helpful suggestions.

The MIT graduate fellowship, the Center for International Studies Fellowship and the Center for Environmental Initiatives Martin Fellowship for Sustainability provided academic support.

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FOREWORD

ESSAYS IN EMPIRICAL ENVIRONMENTAL ECONOMICS: GIS – ECONOMETRIC ANALYSIS OF INDONESIA'S LAND FIRES, BOLIVIA'S DEFORESTATION AND MEXICO'S TRADE WITH THE US

The 1992 United Nations Conference on Environment and Development and the World Bank's World Development Report on the Environment and Development focused attention on the important role of the natural environment in the economy of developing countries. Across the world, developing countries face severe environmental problems. Conflicts often arise between competing users of environmental resources but few mechanisms exist to resolve these conflicts equitably. Environmental degradation exacerbates public health and resource insecurity problems and impairs the public's ability to generate income. The effects of environmental degradation impact the poor disproportionately. Empirical analysis of the socioeconomic aspects of environmental problems in developing countries, however, has made slow progress due to the paucity of data that links environmental measures with socioeconomic ones (World Bank, 1992). This thesis aims to contribute to this research effort. I assemble data from science and social science archives and from the field, apply empirical methods such as geographical information system and econometric techniques, to arrive at policy recommendations.

This thesis examines three urgent environmental issues in developing countries that have global impacts: land fires, deforestation and the pollution intensity of trade patterns. In particular, I examine the role of large and small landholders in Indonesia's 1997 land fires; the potential role of education in reducing deforestation in Bolivia's protected areas and the pollution intensity of US-Mexican trade. Land fires occur in Southeast Asia and the Amazon, and they are severe every 4-5 years during the El Nino enhanced dry seasons (Goldammer, 1999). Tropical deforestation continues at high rates both outside and inside protected areas (World Resources Institute, 2000). Land fires and deforestation affects the global community as they destroy carbon sinks and biodiversity. More recently, globalization efforts have faced protests from a public who believes that trade has led to developing countries' specialization in industries that create more pollution and worker injury (Nordstrom and Vaughn, 1999).

Although the human role in land fires did not receive clear recognition when these fires raged in 1997, the first essay shows that land fires in Indonesia is a case of a negative externality. Taken together, the empirical result that large estates experience greater fire incidence per unit area than that attributed to the naturally dry conditions, the figures that fires are the cheapest way to clear land and the field observations that estates use fires to clear land, suggest that estates gain from the use of fires. However, they ignore the costs from smoke-related health damage and economic disruption borne by the rest of Southeast Asians. Changes in public policy, such as the imposition of penalty on estates that use fires when the risks of fire escape and severe smoke pollution are high, could potentially encourage estates to internalize these costs and to reduce their use of fires.

The next essay examines deforestation in protected areas in Bolivia. Like fires, deforestation in protected areas is a case of a negative externality. Poor households who live in and around forested areas that have been designated as protected areas convert forests for their family farms. They receive no remuneration from the benefits of external watershed protection or biodiversity protection that accrue to other communities. This paper asks whether education, (that the global community who benefit from biodiversity conservation can potentially pay for), can lead to households shifting away from forest conversion. Taken together, the empirical results that the education of the household heads is negatively correlated to the forests cleared, but positively correlated to wages and participation in wage labor (the alternative employment to forest conversion for farming) provide some preliminary evidence, though not causal, of this potential role for education.

The third essay turns to the issue of trade and the environment. It examines the NAFTA-related expansion in US-Mexican trade using new detailed measures of air, water, metal and toxic pollution intensities and injury rates at the 4-digit Standard Industrial Classification level. It does not find strong evidence for greater growth in the shares of net US imports from Mexico in the more polluting or injurious industries between the pre and the post-NAFTA periods. Based on the resolution of pollution measures that is presently available, the empirical evidence does not suggest that Mexico specializes in the more polluting or injurious industries in its trade with the US.

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ESSAY 1

THE ROLE OF LARGE AND SMALL LANDHOLDERS DURING INDONESIA'S LAND FIRES: A GIS-ECONOMETRIC ANALYSIS OF SATELLITE, LAND USE AND SPATIAL DATA

Abstract

Land fires in Indonesia inflict severe air pollution-related damage on all of Southeast Asia annually. Conservative estimates of losses in 1997 alone were US$667 million for Indonesia (0.67% of GDP) and an additional US$12 million for Singapore. This paper studies fire incidence on various landholdings using a new author-compiled database on satellite-based fire and rainfall data, land use maps, socioeconomic and geographical information. It finds that estates, large-scale industrial plantations that are rapidly expanding in the tropics, raise fire incidence beyond the 'natural' level (the fire incidence on conservation areas serves as a benchmark). In contrast, it finds no evidence that small landholdings, which are often blamed for fires, raise fire incidence. The government's ban on the use of clearance fires, as a result of weak enforcement, did not reduce fire incidence on estates. Alternative policy-levers that could potentially reduce these fires, such as lengthening the estates' leases to improve their property security, are found to be ineffective.

1. INTRODUCTION

Land fires inflict significant external costs on Indonesia and Southeast Asia. Fires ravage Indonesia annually, most catastrophically in 1988/9, 1991, 1994 and 1997/8, and they continue to wreak damage this year. The smoke from fires in 1997 caused an estimated 18,330 air pollution-related deaths in parts of Indonesia and other health damage in Malaysia and Singapore.[1] The smoke-related damage which resulted in foregone foreign tourism, transportation disruption and health problems is estimated at US$667.4 million for Indonesia (0.67% of its Gross Domestic Product) and an additional US$12 million for Singapore.[2] In response to these losses, the Indonesian government banned the use of fires to clear land while the Association of Southeast Asian Nations launched a regional plan to reduce smoke pollution that stem from these fires.

This paper provides the first empirical tests on how the different landholdings (or land use types) affect the incidence of fires and investigates the effectiveness of Indonesia's regulatory efforts and other policy levers for fire reduction. Based on the economic incentives they face, landholders choose either more or less flammable types of agricultural production technology, and thus they influence the fire incidence (per unit area) on their land. Previous studies have not isolated the effect of various land use types on fire incidence (Hoffman et al, 2000; Stolle et al, unpublished). As a result, fires have been blamed on El Niño exclusively, or on small landholders, or on large landholders[3] (Kompas, 1997; Vayda, 1998; Glover & Jessup, 1999).

With the expansion of estates in developing countries, estates' potential contribution to land flammability is an important question. If estates raise fire incidence, their expansion without efforts to discourage the use of fires would lead to greater fire incidence and more smoke pollution. Facing options in their agricultural production technology and difficulties in enforcing laws against pollution similar to those of other developing countries in Southeast Asia, Indonesia serves as a case study of the consequences of estate expansion in its present form. Governments, lending agencies, environmental groups, and private corporations are promoting estates for export earnings (Casson, 1996), for reforestation and timber supply (Mayer, 1996b), and for use as

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[1]This figure is based on a conservative recalculation of WHO (1999).
[2]These figures are based on conservation recalculations of Ruitenbeek (1999), Hon (1999) and ADB-BAPPENAS, (1999).
[3]The position of former President Soeharto and of the Government of Indonesia the 1997 fires on El Niño (Kompas, 1997); the discussions during the Association for Southeast Asian Nations (ASEAN) Haze Action meeting blamed small landholders (Vayda, 1998); while the World Wildlife Fund-Indonesia blamed 80% of the fires on estates (Glover & Jessup, 1999).

potential carbon sequestration projects (Moffat, 1997; Lohmann, 1999). Within Indonesia itself, an area the size of Belgium has been designated for new estate development (Casson, 1999), while the International Monetary Fund's (IMF) recent policy recommendations may lead to further estate expansion (GoI, 1998).

I study which landholders – small or large – experience greater fire incidence on their land than the benchmark of 'natural' fire incidence, using a database that I have compiled on satellite-based fire hotspots and rainfall data, maps of land use and geographical features, and socioeconomic data. These data are organized into a Geographical Information System. The fire incidence of various land use types is compared with that of conservation areas (the benchmark for the 'natural' fire incidence), controlling for other factors that influence flammability. The potential econometric estimation problem of the selective placement of estates and conservation areas is addressed using a linear fixed-effect model (between 1992 and 1997) and a neighbor/matching model that compares estates with nearby conservation areas. Standard errors are corrected for spatial error.

The rest of the paper is organized as follows. Section 2 reviews the economic choices of flammable technology; Section 3 describes the data; Section 4 outlines the empirical framework for the analysis of fire incidence on various landholdings; Section 5 reports the results; Section 6 analyzes the effectiveness of enforcement and other policy levers; Section 7 conducts a limited cost-benefit analysis on the use of fires on estates; and Section 8 concludes and makes policy recommendations.

2. ECONOMIC CHOICES OF FLAMMABLE TECHNOLOGIES

The land use types in Indonesia are large landholdings, small landholdings (small farmers) and conservation areas. Conservation areas are sites set aside for watershed and biodiversity protection throughout Kalimantan (Indonesian Borneo), the study site. Large landholdings are logging areas, estates, transmigration areas (government-sponsored large-scale resettlement projects that provide land for migrants).

This study examines the fire incidence on landholders' own land parcels because such fires, even when they do not spread to neighboring land parcels, cause smoke pollution.[4] Man-made fires occur if landholders choose to use flammable production technologies, in order to save labor and capital costs, despite the increased risk of fire spreading to areas that are of value to them. Landholders who face penalties will also consider the risks of fire spreading to their neighbors and the costs of smoke production. Small landholders in communities with functional social norms face penalties if fires spread to their neighbors' lands (Colfer, 1999). In contrast, despite a field report that an estate caused fires in small landholder areas (Goenner, 1998), estates have faced no penalties (Harwell, 2000).[5]

Man-made fires in logged areas would occur as a side-effect of logging activities. Technologies that are cheaper in labor and capital costs lead to greater post-logging flammability. Man-made fires occur in transmigration projects if fires are used by government-hired contractors who clear land designated for these projects or by migrants who clear the land to plant new crops. Man-made fires on estates and small landholdings would result from the use of fires to clear land to plant new crops (Goenner, 1998). In selecting among land clearance technologies, estates and small landholders choose the level of caution to be exercised against fire spreading (including choosing a non-fire method to clear land). Purchasing more caution would require more labor and capital expenditure, but would reduce the risks of fires escaping.

A priori, it is unclear whether small landholders or large estates are more likely to use less caution, and hence, whether small landholdings or estates exceed the 'natural' fire incidence. Small landholders and large estates both face incentives and disincentives to choose less caution. For example, small landholders' weaker property rights compared to those of estates[6] lead small landholders to choose less caution. Intuitively, because they are more likely to lose the land after clearance, they are less likely to pay the full cost of non-fire land clearance. On the other hand, small landholders' greater proportion of wealth exposed to the spread of fire compared with that of estates leads small landholders to choose more caution.[7] A simple model of the small and the

[4]Fires that spread to neighboring land from fire-prone land use types would cause additional social costs, and understanding the costs of such fires would be an interesting extension of this study.
[5]I found no reports of fires spreading into an estate from another estate or from small landholdings.
[6] While the government provides estates with 30-year leases, it does not recognize any rights for small landholders, often granting land occupied by small landholders to estates and logging companies, without consulting the small landholders or providing compensation (Barber, 1998; Potter and Lee, 1998b)
[7]Small landholders' huts and fields are close to the land to be cleared (Colfer et al, 1997). In contrast, corporations that generally own estates have investments in diverse areas (Casson, 1999).

large landholder's choice among more and less flammable technologies is presented in Appendix 1.

3. DATA

The study area is Kalimantan (the Indonesian part of the island of Borneo) that extends to about 435,000 km^2 in size. One of the 5 larger islands in Indonesia, Kalimantan borders important shipping-lanes that include those for oil shipments and that connect Europe, the Middle East, and Southeast Asia with the Far East and Australasia. Urban areas are excluded because forest and land fires do not occur there.

Various maps are arranged into layers within the Geographical Information System (GIS). The base map is split into grid cells of 0.01 degrees by 0.01 degrees (about 1 km^2). Each grid cell is assigned the values of three types of variables from the map layers in the GIS: (1) the fire variable to be explained; (2) the explanatory variables of interest (the land use types and the density of shifting cultivation); and (3) control variables. Unless stated otherwise, all variables are at 1 km^2 resolution, corresponding to the resolution of the fire variable. Data sources are listed in Appendix 2.

Fire hotspots

The fire variable is a dummy variable that takes the value 1 if at least one fire hotspot is detected in a cell during the period of study. This study uses satellite-based Advanced Very High Resolution Radiometry data, the standard data used for fire detection worldwide (IGBP). Even fires in small landholdings are detected, as the size of the minimum detectable fires [beyond 30 meters (Setzer, remote sensing specialist, pers. comm.)] is greater than the size of small landholdings [1.7-2.1 hectares (Colfer et al, 1997)].

The data has been processed using the contextual and single threshold algorithms (for day and night-time detection, respectively) that relate the cells' brightness temperature in the mid-infrared and thermal channels to the presence or absence of fire hotspots in those cells (Flasse and Ceccato, 1996; Justice et al, 1996). Fire hotspots are detected two or three times a day, almost every day for the most part of the fire season (between the last week of July to the end of November in 1992 and 1997, respectively).

The analysis of the fire incidence on various land use types would be biased only if the errors in fire detection were systematically correlated to the types of land use. One such example is if persistent cloud cover prevented fire detection, and conservation areas were systematically located in high elevation areas with persistent cloud cover. To address this source of bias, this study includes elevation as a control variable and employs a neighbor model that restricts the analysis to observations of estates and conservation areas that lie close together.

Land use variables

The variables of primary interest are a series of exclusive land use dummies that take the value 1 for one of the following land uses: (i) estates, (ii) logging concessions, (iii) transmigration areas, (iv) conservation areas and (v) small landholdings. Land use maps in 1992 and 1995 are constructed from maps of estates, transmigration areas, logging concessions and conservation areas. Because the trend of land use change is toward the development of land, areas that are released for logging, estates and transmigration areas do not revert to their original uses. Some of the 1992 logging areas, logging and smallholdings areas turned into estates or transmigration areas by 1995, but not vice versa. The 1995 land use, the most recent publicly available information, is used to represent the 1997 land use.

Small landholdings are the default land use category: maps are unavailable. As a result, some grid cells may be mislabeled as small landholdings, including (1) cells that are unpopulated and (2) cells that switch into estates or transmigration areas between 1995 and 1997. The inclusion of the former could lead to underestimates of the effect of small landholdings on fire incidence, while the latter, if estates raise the fire incidence on land, would lead to overestimates of such an effect. The potential problem from the unpopulated cells is minimized because the regression models compare estates with small landholdings that lie on comparable elevation, and estates generally lie in lowland Kalimantan that is fairly populated.

An additional variable of interest is the density of shifting cultivation in small landholding areas at the district level in 1991 and 1995 (obtained from Indonesia's Central Bureau of Statistics). This density of shifting cultivation in a cell of 'small landholdings' is the ratio of (a) the area of shifting cultivation in a district to (b) the area of 'small landholdings' in that district. Data at this poor resolution are the best available.

Control variables

(1) The 1997 rainfall data are based on 1-degree resolution microwave-infrared (MV-IR) satelite data. The 1992 rainfall data are generated from Janowiak's 2.5 degree resolution outgoing longwave radiation (OLR) satellite data, using the statistical relationship in meteorology (Janowiak and Arkin, 1991). These coarse resolution data are the only rainfall data readily available for large areas of Kalimantan. As the data cannot detect orographic rainfall, i.e., rain that occurs on the raincloud-facing slopes in mountainous terrain, elevation variables help control for this type of rainfall.

Other information available for the cells is their (2) elevation; (3) the presence or absence of peat soil; (4) the linear distances from each point to the closest rivers and roads [calculated using maps of rivers and roads]; (5) vegetation type; (6) population at the sub-district level. Maps provide the information for the first four variables, while the census provides the population data at the sub-district level.

4. THE FIRE INCIDENCE IN VARIOUS LANDHOLDINGS: EMPIRICAL FRAMEWORK

4.1 IDENTIFICATION STRATEGY

To isolate man's contribution, if any, to fires on a type of land use or landholdings (e.g., estates), the actual fire incidence on estates that resulted from both man-made and natural fires could be compared with the counterfactual fire incidence if only 'natural' fires had occurred there. This benchmark 'natural' fire incidence is estimated using the fire incidence on cells that are conservation areas but that are otherwise comparable to estates in their observed characteristics. This estimation strategy can be used because conservation areas, like other land use types, experience human perturbation and therefore experience comparable 'natural' fire incidence. Nevertheless, this strategy provides a lower bound estimate of man's contribution to fires, because conservation areas suffer from some level of encroachment-related (Ryan, 1998; Newman 2000) man-made fires.

Two potential estimation problems arise in using the fire incidence of conservation areas as a benchmark. First, conservation areas may receive more effective national fire suppression efforts than do other land use types. In practice, however, these efforts, such as water bombing and cloud seeding, were ineffective (Schindler, team-leader of the GTZ-fire project, cited in Kompas, 21/4/1998; the then-Forestry Minister, cited in Kompas, 6/2/1998, UN-Disaster Assessment, 1997).

Second, estates could have been selectively placed in areas that are degraded and thus are inherently more flammable than conservation areas. The panel and neighbor models (Section 4.4 and 4.5) are used to address this potential selection bias. Moreover, in practice, estates have located on less degraded lands, including in the north of the East Kalimantan province (Momberg et al, 1998) and in the province of Kalimantan Barat (Potter and Lee, 1998b). Location of estates in less degraded areas has also been reported by government officials and non-government organizations (Potter & Lee, 1998b). The estates' application for licenses to clear-cut timber provide additional evidence that their land contains valuable timber and is thus less degraded (Potter and Lee, 1998b). In contrast, the delineation of several conservation areas has included areas that are degraded and excluded areas that are less degraded (Bennett, researcher in Indonesia, pers. comm.).[8]

One other methodological issue is the interpretation of the findings if a particular land use type, e.g. estates, exceeds the 'natural' level of fire incidence. Such a finding could mean that either (1) all firms in that land use sector face incentives to use fires, or (2) only particular firms can enter that land use sector and these are the firms that are more likely to ignore social costs. However, the former explanation is more likely. The share of estates firms without connections to the former President Suharto is substantial[9] (32%) (Wakker, 1999); and even Suharto's business partners, who broke norms or laws, faced penalties from the reform factions within the government and from Suharto himself (Poffenberger, 1996).[10]

Three regression models are used, each making slightly different assumptions: (1) the cross-section model; (2) the linear fixed effect model; and (3) the neighbor model.

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[8]The delineation of the Bukit Baka Bukit Raya conservation area purposefully included large areas of degraded land.

[9]These firms include 43 Malaysian-Indonesian joint ventures that own 1.1 million hectares and intend to develop an additional 1.5 million hectares (Wakker, 1999) and foreign investors such as the Belgian Franco SOCFIN and the British LonSum (54,000 hectares).

[10] Soeharto limited the transgressions of these firms, as they eroded his legitimacy (Poffenberger, 1996).

4.2 CROSS-SECTION MODEL

The cross section model compares, across rural Kalimantan, the fire incidence on various land use types with that on conservation areas, controlling for observed geographical and socioeconomic variables that influence fire incidence. The presence of fire incidence in a cell is a function of the land use type and a host of geographic and socioeconomic variables in that cell. F is a dummy variable that records whether a fire hotspot occurs in a cell, L is the vector of dummies for land use types, S is the density of shifting cultivation, G is a vector of geographic variables, and E is a vector of socioeconomic variables. The fire incidence in a cell *i* is given by,

$$F_i = f(\ L_i, S_i, G_i, E_i)$$

$$F_i = X_i \alpha + \varepsilon_i \qquad \text{(Equation 1)}$$

where X is a vector containing L, S, G and E, β is a parameter vector, and ε is the standard normal error term. Ordinary Least Square (OLS) is used for the estimation.[11]

As the land use category that is excluded from the regression model is the dummy for the conservation area, the coefficient of a given land use variable estimates the effect of a given land use on fire incidence net of the fire incidence in conservation areas. The geographic variables that influence flammability are rainfall, elevation, soil type and vegetation type. Greater rainfall and high elevation lead to fewer fires. Peat soil is flammable when dry, thus, a dummy variable is used for the presence of peat soil. The vegetation types, which proxy for the ecosystem types, are used to provide further controls for geographical factors that influence flammability. Dummy variables are used for the different vegetation types, i.e., montane, lowland, swamp, mangrove and unclassified vegetation. The socioeconomic variables that influence flammability are population density, distances to roads and rivers and dummy variables for the 4 provinces in Kalimantan. Omitted variables, as long as they are not systematically correlated to land use types, e.g. wind speeds, do not bias estimates of the effect of land use on fire incidence.

4.3 SPATIAL CORRELATION

This paper is interested in the following estimate: after any potential propagation effects among cells, which land use types experience fire incidence beyond the natural benchmark. The coefficient for the estate variable measures the total effect of estates on the fire incidence, stemming from (1) the effect of estates on the initial ignition in that cell, ©, and (2) the increased susceptibility of that cell from ignition from its neighbor as a result of that cell, ©, switching into estates. Because the observations are cells in a continuous space, spatial correlation is likely to be present.

For the cross section and linear fixed effect model, robust standard errors clustered on districts allow errors to be correlated across districts. For the neighbor model, Conley's estimator is used to estimate the spatial error corrected standard errors (Conley, 2000). Conley's estimator (a Generalized Method of Moments estimator) is analogous to the Newey-West serial autocorrelation corrected standard errors used in time series econometrics. Using a moving and expanding 'window,' Conley's estimator takes into account the spatial autocorrelation among a cell and cells that lie within x cells in the latitude and y cells in the longitude directions. Interestingly, the size of most of the clusters of fire hotspots is very small, with 88.2% of the clusters containing 4 cells or fewer (Table 4.1).

4.4 PANEL MODEL

An estimation problem arises if the type of land use in a cell is selected based on omitted variables that are correlated with the fire incidence, such as land quality. Instead of equation 1, the underlying model would be given by,

$$F_i = X_i \alpha + u_i + \pi_i \qquad \text{(Equation 3)}$$

where u_i is the omitted variable on which the selection is made (and π is a standard normal error term). Because the correlation between X_i and u_i, and the correlation between F_i and u_i are both non-zero, the estimates of α are biased.

One method to address this potential selection bias is to estimate a linear fixed effect model, which uses repeated observations for cells to control for unobserved time invariant factors that are correlated to the fire incidence and the land use type. The linear fixed effect model (Equation 6), by subtracting Equation 4 from Equation 5, removes u_i and thus, allows the unbiased estimation of the effect of land use type on fire incidence (α).

[11] The linear probability model and the probit model give similar estimated coefficients for the cross-section model. The predicted values in the cross section model and the neighbor model are 88% and 94% within the [0,1] probability range. Therefore, OLS is used for tractability.

$$F_{it} = X_{it}\alpha + u_i + \pi_{it} \qquad \text{(Equation 4)}$$

$$F_{i\,t+1} = X_{i\,t+1}\alpha + u_i + \pi_{i\,t+1} \qquad \text{(Equation 5)}$$

$$\Delta F_i = \Delta X_i\,\alpha + \rho_i \qquad \text{(Equation 6)}$$

The effect of the cells changing into the land use type of estates is identified by the switch of cells from non-estates in 1992 to estates in 1997. Cells switch from non-estates to estates but do not revert from estates to non-estates, as a result of the trend of land use changes in Indonesia. As a result of data constraints, the linear fixed effect model examines the fire incidence in 1997 and 1992, using fire hotspots from 1997 and 1992, but using land use maps from 1995 and 1992, respectively. The model includes a dummy for 1997 as the 1997 fire season was much drier than the 1992 one (D_{97}). The linear fixed effect model that is estimated is

$$\Delta F_i = \Delta X_i\,\alpha + D_{97i}\,\gamma + \pi_i \qquad \text{(Equation 7)}$$

The coefficient on the change in the presence of estates variable, $\alpha_{estates}$, estimates the effect of estates on the fire incidence. Although the fixed effect model cannot address selection that is based on time-varying omitted variables, evidence reviewed above suggest that estates are not likely placed systematically in less degraded areas. Estimation problems arise in the fixed effect model if cells that burn in 1992 are more likely both to turn into estates and to burn again in 1997. However, the low correlation between the presence of hotspots in 1992 with the presence of new estates in 1997 means that this is not a serious problem. Moreover, the cells that switched into estates by 1997 were not originally more fire-prone in 1992 than the cells that remained conservation areas or small landholdings (Table 5.5).[12]

Another potential problem arises if the linear fixed effect model captures the effect of cells switching into a new land use type and not necessarily the effect of cells switching into estates per se. To check for this "new" land use type effect, the cross-section model is re-estimated with estates and transmigration areas partitioned into recent and older estates or transmigration sites. High fire incidence in older estates would indicate that estates, and not new land uses per se, increase fire incidence.

[12] Although the cells that switched from logging areas to estates appear more fire-prone originally in 1992 than do cells that remained as logging areas, the former still experience a greater mean increase in fire incidence between 1992 and 1997 than do the latter.

4.5 NEIGHBOR MODEL

The neighbor model provides an additional method of addressing the potential selection bias that arises from the possible placement of estates in more degraded areas. It controls for unobserved land quality by comparing estates with nearby conservation areas (within 50 km) which are likely to have similar land quality. The neighbor model is essentially a matching technique in which the treatment groups are matched with control groups that share similar characteristics. Here, estates are matched with conservation areas in the same neighborhood because their land quality is likely to be similar. A neighborhood is defined as an area that contains (1) estate cells and (2) conservation area cells that lie within 50 km from the estate cells. The underlying model is that for each cell i in neighborhood j, cells that lie within the same neighborhood whether estates or conservation areas share the same u_j.

$F_{ij} = X_{ij}\,\alpha + u_j + \pi_{ij}$ (Equation 8)

The addition of a dummy variable for each neighborhood (or a neighborhood fixed effect) absorbs the neighborhood specific land quality (D_j), and thus provides unbiased estimates of α. The neighbor model estimated using OLS is:

$F_{ij} = X_{ij}\,\alpha + D_j\,\gamma + \pi_{ij}$ (Equation 9)

The omitted land use category in the neighbor model is conservation areas. The coefficient on the estates, $\alpha_{estates}$, measures the effect on estates on fire incidence net of the fire incidence on conservation areas. The use of the neighborhood specific fixed effect controls for spatial correlation among cells within the same neighborhood (Deaton, 1987). In addition, Conley's spatial error corrected standard errors (Conley, 2000) are estimated.

5. FIRE INCIDENCE IN VARIOUS LANDHOLDINGS: RESULTS

To obtain a general overview of the fire incidence across rural Kalimantan, the mean hotspots in various landholdings are tabulated. The mean hotspots is the ratio of the number of cells in a land use type that registers fire hotspots to the sum of cells in that land use type. These naïve comparisons of the mean hotspots in various landholdings are listed in Table 5.1. Comparing the mean hotspots in estates with that in conservation areas in 1997 reveals that estates experience 5-fold the level of fire incidence in conservation areas [column 5: $(11.8 \div 2.1)$].

To determine the effects of land use on fire incidence, three models are estimated, each applying slightly different assumptions to control for confounding factors. The cross section model compares estates (or other land use types) with conservation areas that are otherwise similar in their characteristics, and controls for other socioeconomic and geographical factors that influence flammability. The results from the cross-section model are reported in Table 5.3. A comparison of the coefficient of the estate variable with the mean hotspot in conservation areas (0.021) shows that estates raise fire incidence by 0.050 percentage points or 3.4-fold that in conservation areas [(0.050+0.021) ÷0.021].

To address confounding effects from the potential selective placement of estates in more degraded areas, the fixed effect model and the neighbor model are estimated. The fixed effect model examines the effects of cells switching from one land use to another between 1992 and 1997 and thus controls for time invariant unobservables such as the time invariant component of land quality. The results from the fixed effect model are reported in Table 5.4. Comparing the coefficient on the estate variable with the increases in mean hotspots in conservation area between 1992 and 1997 (0.016) reveals that estates raise fire incidence by 0.040 percentage points or 3.5 times the change in fire incidence in conservation areas between 1992 and 1997.

Another way to examine these changes across time is to compare the mean increase in fire incidence between 1992 and 1997 for two types of cells: (1) cells that switch into estates (from conservation areas, logging areas or small landholdings) and (2) cells that remained conservation areas, logging areas or small landholdings, respectively. These results are reported in Table 5.5. Cells that switch into estates experience greater fire incidence than cells that remained in the original land uses. One concern in the interpretation of the fixed effect model is that it may capture the effect of cells switching into any new type of land use, and not necessarily the effect of cells switching into estates. Nevertheless, the findings that both older and more recent estates (Table 5.6) experience high fire incidence suggest that estates, and not just any new land use type, increase fire incidence.

Another estimation method to control for the confounding effects that arise from the selective placement of estates in more degraded areas is the neighbor model. By restricting the comparison between estates and nearby conservation areas, the neighbor model controls for land quality that is similar in areas closer in space. The results from the neighbor model are reported in Table 5.8. Comparing the coefficient on the estate variable with the mean hotspots in conservation areas in the neighbor model (0.063) shows that estates raise the fire incidence by 0.058 percentage points or by twice that in the conservation areas [(0.058+0.063)÷0.063]. As the summary statistics of conservation areas and estates (Table 5.7) suggest that they are similar in their characteristics other than their land use and their fire incidence, these findings suggest that estates indeed raise fire incidence.

In contrast to the findings on estates, the cross-section and first difference models find no evidence that small landholdings exceed the 'natural' benchmark. Nevertheless, the potential mislabeling of some unpopulated cells as small landholdings cells could have led to underestimates. The study also does not find evidence that logging and transmigration areas raise fire incidence beyond the 'natural' benchmark. Nevertheless, logging areas, even though they do not experience high fire incidence per unit area, contain the largest number of fire hotspots, because they occupy the greatest land area.

As a check of confidence in the estimation models, it would be useful to examine the coefficients whose signs are known a priori. The estimates for rainfall, elevation and the presence of peat have the expected signs, and thus encourage confidence in the estimation models. The cross-section model (Table 5.3) finds that higher rainfall and elevation reduce fire incidence, while the presence of peat soil raises fire incidence. The neighbor model (Table 5.8) finds that higher rainfall and elevation reduce fire incidence. The fixed effect model (Table 5.4) finds that the 1997 year dummy is associated with greater fire incidence, consistent with dryness in that year.

To summarize, the empirical analysis that best controls for potential selection bias finds that estates raise fire incidence beyond the 'natural' level. In contrast, this study, albeit using a less powerful test, finds no evidence that small landholdings raise fire incidence beyond the 'natural' level. These results imply that estates make significant contributions to the current fire incidence and smoke pollution and that the planned expansion of estates, unless they are discouraged from the use of fires, would increase fire incidence and worsen smoke pollution in Southeast Asia. The smoke pollution costs from estates are reported in Section 7 and 8.

6. EMPIRICAL ANALYSIS OF THE PAST ENFORCEMENT EFFORTS & OTHER POLICY LEVERS

6.11 WERE PREVIOUS ENFORCEMENT EFFORTS EFFECTIVE?

In light of the above findings on estates' contribution to fire incidence, this section examines whether previous enforcement efforts reduced fire incidence on estates. Although the use of clearance fires (except in conservation areas) had been legal (MoE-UNDP, 1998 and Gellert, 1998), on September 9, 1997, the government banned the use of fires. The then-President Suharto announced that (1) the use of fires was banned, (2) landholders should not allow burning to occur on their landholdings, and (3) enforcement attempts would be stepped up (Kompas, 09/10/1997).

To determine whether the ban was effective, its effect must be distinguished from the effect of the weather on the pre-ban and post-ban fire incidence. Therefore, "a difference in difference" estimation strategy is used. To extract the ban's effect on estates, I subtract (a) the difference in the pre-ban and post-ban fire incidence on conservation areas (that is, differences due to the weather) from (b) the difference in pre-ban and post-ban fire incidence (that is, differences due to both the weather and the ban).[13] The estimation model is:

$$F_i = L_i \beta + B_i \mu + (L_i * B_i) \nu + Z_i \delta + \varepsilon_i$$

where B is an indicator variable that takes on the value 0 before the ban is in force, and 1 after the ban is in force; L is a vector of land use dummies; (L * B) is a vector of land use dummies interacted with the ban variable; Z is a vector of socioeconomic and geographical variables that influence flammability. The periods of August 1, 1997 to September 9,1997 and September 10, 1997 to October 20, 1997 are taken as the periods before and after the ban, respectively.

As the omitted land use category is conservation areas, the coefficient of the ban variable, μ, captures the additional fire incidence on conservation areas after the ban compared to the pre-ban fire incidence. The coefficient of the product of the dummy on the presence of estates and the ban dummy, $\nu_{estates}$, captures the additional fire incidence on estates after the ban compared to the pre-ban fire incidence, using the difference in the pre-ban and post-ban fire incidence on conservation areas as a benchmark. The result that this coefficient is not significantly negative (Table 6.1) indicates that the ban did not reduce fire incidence on estates.

[13] If encroachers in conservation areas responded to the ban by reducing their use of fires, it would be difficult to analyze the effect of the ban. Nevertheless, such a behavioral response may not have occurred, as increased post-ban government enforcement efforts in conservation areas have not been reported.

6.12 WERE ENFORCEMENT EFFORTS EFFECTIVE IN MORE POPULATED AREAS?

If past enforcement efforts had reduced the fire incidence on estates in more-populated areas relative to that on estates in less-populated areas, they would have reduced the exposure of highly populated areas to smoke, and thus would have reduced total smoke-related health damage. To determine if estates in highly-populated areas experience less fire incidence than those in less-populated areas, the following model is estimated:

$$F_i = L_i \beta + H_i \mu + (L_i * H_i) \nu + Z_i \delta + \pi_i$$

where H is an indicator variable that takes on the value 1 for high population density areas and the value 0 otherwise; L is a vector of land use dummies; (L * H) is a vector of land use dummies interacted with a high population density dummy; Z is a vector of socioeconomic and geographical variables that influence flammability. The coefficient of the product of estate dummy and the dummy for high population density, $\nu_{estates}$, captures the additional incidence of fires on estates in highly-populated areas. The result that this coefficient is not significantly negative indicates that estates in high population areas did not experience lower fire incidence (Table 6.2).

6.13 WERE PAST ENFORCEMENT EFFORTS WEAK?

The failure of the ban to reduce fires on estates is unsurprising, as the enforcement efforts were weak. The government did not prosecute any estates between 1997 and 1998 (Harwell, 2000), fine them or revoke their operating licenses (WALHI, an Indonesian NGO, cited in Kompas, 05/14/1999). Its release of the names of firms suspected of using fires (Environmental Investigation Agency, 1998), given the absence of negative consumer and public action in Indonesia or abroad, did not inflict costs on the firms.[14] Its revocation of the firms' timber-cutting licenses did not interfere with the estates' core operations (even these were reinstated by December 1997) (Waluyo, 2000). Despite a researcher's compelling evidence that an estate used fires, the local police did not prosecute the estate, citing the lack of evidence[15] (Goenner, 1999).

[14]This paper does not advocate blunt and counterproductive overseas consumer action against Indonesia's oil palm exports.

[15]Goenner (1998) reports an eyewitness account of employees of an estate company coming from the direction of burning land patches carrying petrol cans. Fires are likely to have started from within these patches that were surrounded by cleared land. The estate firm, which intended to expand their operations onto this land, stood to benefit from these fires as they had to pay less for burned land to the local community.

Only in 1999, were 2 of the estates accused of causing fires in 1997-8 actually prosecuted (Jakarta Post, 08/05/1999).

In contrast, local authorities have fined and jailed several groups of small landholders in the province of East Kalimantan (GTZ-SMFP, 1997-8) but whether their actions were based on strong evidence remains unanswered.

6.2 ALTERNATIVE POLICY LEVERS TO REDUCE FIRES

6.21 LENGTH OF ESTATE LEASE

One potential policy lever to reduce fires on estates is to lengthen the estates' leases. Firms close to the end of their leases face property insecurity, as the renewal of these leases is uncertain, and thus they are less likely to consider the long-term benefits of using fires, such as maintaining soil fertility. The number of years that remain on a lease is the difference between 30 (the total length of leases in general) and the number of lapsed years between 1997 and the year when an area is released to the estate firm by the Ministry of Forestry. Because firms generally develop their estates in stages of sub-parcels, it is less likely that a cycle of production effect (in which the age of the estates is correlated with the use of clearance fires) would significantly compound the effect of the lease on fire incidence. Chart 6.3 finds no clear relationship between the remaining years on the estates' leases and the percentage of cells on estates that register hotspots. The remaining years on the leases do not influence fire incidence, most likely because all firms still have 20-30 years, a substantial period, remaining on their leases.

6.22 ESTATE SIZE

The size of estates could potentially influence fire incidence, though a priori its effect is ambiguous. On the one hand, firms may face economies of scale in mitigating fires as a result of the fixed costs of fire suppression equipment. On the other hand, firms may face greater coordination problems in mitigating fires if estates are too large. The estimation model is:

$F_i = S_i \beta + Z_i \delta + \pi_i$ where i are estate cells, S is the size of the estate and Z is a vector of control variables.

The resulting coefficient on estate size indicates no significant effect. However, estate size may be endogenous if firms with better political connections are able to obtain larger sized concessions and anticipate less enforcement against the use of fires.

7. THE COSTS AND BENEFITS OF THE USE OF FIRES ON ESTATES

The benefits from the use of fires to clear land are the savings realized from the use of cheaper fire methods instead of alternative non-fire methods. Table 7.1 tabulates the labor and capital costs of controlled burning as well as those of the cheapest non-fire land clearance methods.[16] These figures from oil palm estates reveal that the benefits from the use of fires per hectare of estate burned range between US$12.5 to US$33.8 (Wakker, AID Environment, pers. comm.) or even as high as US$41.3 (ADB-BAPPENAS, 1999).

The costs from the use of fires on estates are the smoke pollution costs, including health, tourism and transportation losses and they are borne by Indonesians and other Southeast Asians (Malaysians, Singaporeans, people of Brunei and Southern Thais). The total smoke pollution-related losses borne by Singapore and Indonesia as a result of all biomass burning in Sumatra and Kalimantan are estimated in Table 7.2. The portion of these losses that is due to burning on estates in Kalimantan is then calculated (the last row in Table 7.2). These losses are finally expressed in terms of losses per hectare of estate burned (Table 7.3). Table 7.4 then compares these costs with the benefits from using fires on estates.

The most conservative cost figures value only the pecuniary aspects of lives lost by valuing a life at half the foregone lifetime earnings. These conservative estimates suggest that smoke-pollution costs from each hectare of estate burned in Indonesia range between US$26.8 and US$44.7 for Indonesia and between US$28.9 and US$48.1 for both Indonesia and Singapore (Table 7.3). Although these conservative cost estimates appear comparable to the benefits, these figures severely understate the actual health costs and thus do not provide good guidance for policy-making.

A more appropriate and widely accepted method for valuing life is the Value of Statistical Life method (VSL) because it accounts for the additional non-pecuniary aspects of life (Viscusi, 1993).[17] This method reveals that the cost ranges between US$116.8 and US$194.7 for

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[16]Non-fire methods provide additional reduced fertilizer input, reduction of erosion and siltation of drains; but require additional expenditures such as the planting of leguminous cover to prevent outbreaks of rhinoceros beetle and wildfire and ploughing to avoid basal stem rot infections (Wakker, 1999).

[17]The VSL method has replaced foregone wage methods for estimating the value of life in the US (Viscusi, 1993). VSL methods assume workers make risks tradeoffs, in which they receive a wage premium for

Indonesia and between US$118.9 and US$198.2 for both Indonesia and Singapore. These figures still underestimate the actual health costs as they have not included the long-term health costs for Singapore, Malaysia and Southern Thailand. Nevertheless, using even these low estimates of the health costs reveals that the use of fires clearly inflicts net costs on Indonesia and Southeast Asia.

Another aspect of the costs from the use of fire versus non-fire methods is the additional release of carbon dioxide when fire methods are used, but these figures are unavailable. Instead, the estimates are based on the contribution of estates to the net carbon dioxide released in 1997 (Table 7.2.). Accounting for these emissions costs shows that the use of fires inflicts even greater net costs on the global community.

The costs-benefits analysis above suggests that, even using fairly low estimates of health costs (using the standard Value of Statistical Life method), the costs from the use of fires exceed the benefits. The actual costs from fires are likely to be greater, if the mortality among Singaporeans and Malaysians that resulted from their exposure to smoke had been included. Policy-relevant equity issues also arise as those who suffer from air pollution in Indonesia are typically the poor who work outdoors and cannot afford preventative measures, while those who benefit from the use of fires on estates are the wealthier owners of estates. Without mechanisms to compensate those who suffer from smoke pollution, tolerating fires would not be economically efficient even if fires had resulted in net benefits.

8. CONCLUSION AND POLICY RECOMMENDATIONS

The empirical analysis finds that estates raise the fire incidence beyond the benchmark of 'natural' fire incidence. In contrast, it finds no evidence that small landholdings that have often borne the blame for fires exceed this benchmark. Although the government banned the use of fires for land clearance, as a result of poor enforcement efforts, the ban did not reduce fire incidence on estates. Alternative policy levers for reducing fires on estates, for example, lengthening their leases to improve their property security, are ineffective as estates have long periods (20-30 years) left on their leases. These results have four implications.

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willingness to face greater work-related hazards. Nevertheless, even this method underestimates the value of life if workers are not making free and informed choices.

First, estates contribute significantly to smoke pollution-related costs, even when conservative estimates of costs are used. In 1997 alone, they:

- caused at least 935 air pollution-related deaths (these figures include only Kalimantan, East Java and 4 out of 8 provinces in Sumatra).
- caused at least US$7.8 million worth of losses to Indonesia (0.008% GDP) and an additional US$0.6 million to Singapore, as a result of foregone tourism earnings, disrupted transportation and health expenses, caused by smoke pollution. [18]
- emitted an equivalent of one tenth of France's net annual carbon dioxide emissions, emissions costing US$357 million.[19]

Second, the planned expansion of estates in the tropics, unless estates are discouraged from using fire, would lead to greater fire incidence and greater smoke pollution. Several policies will lead to estates' expansion: (1) the Indonesian government's plans to open an additional 3.1 million hectares of estates (an area the size of Belgium) by 2000[20] (Wakker, 1999); (2) the International Monetary Fund has recommended that the estate sector be opened to foreign investors; and (3) governments, corporations and environmental groups are currently pushing to develop large-scale estates for cash crops, reforestation and carbon sinks in Southeast Asia and elsewhere in the tropics. To date, environmental groups that promote carbon sinks and reforestation have not considered the possibility that firms contracted to expand estates may use fire to clear existing scrubs in order to plant tree estates and thus counterproductively contribute to negative environmental impacts.[21]

Third, Indonesia's stated zero-burn policy (in its agreement with ASEAN) will not be achieved without changes in its current enforcement policies. Under the present weak measures, estates use fires because they are the cheapest method for clearing land (if social costs are

[18]These are conservative lower-bound re-estimates of figures in WHO (1999), ADB-BAPPENAS (1999), Ruitenbeek (1999) and Hon (1999).

[19]Estates contribute 5.1% of the gross carbon dioxide emissions from biomass burning in Sumatra and Kalimantan (Levine, 2000). Ideally, the cost-benefit of the use of fires on estates should compare the additional carbon released by the fire versus the non-fire land clearance methods. The use of fire methods leads to additional carbon sequestration by burning soil organic matter (SOM) that is abundant in peat soil and by increasing nutrient-losses through soil erosion and thus reducing plants' ability to sequester carbon. However, these figures are not readily available.

[20]Indonesia's economic and political instability has delayed the achievement of this goal (Wakker, 1999)

[21]Environmental groups, who promote tree estates, would have to monitor the activities of firms to discourage their use of fires. Otherwise, firms may use the cheaper burning techniques, but blame the fires on dry conditions.

disregarded) and their estimated savings from the use of fires range between US$12.5 to US$33.8 per hectare, or even as high as US $41.3 per hectare (Wakker, pers. comm.; BAPPENAS, 1999).

Stronger enforcement and sufficiently large penalties would encourage estates to switch to non-fire clearance technology. A precedent for such measures is in Malaysia, where penalties against the use of fires were strictly enforced in 1997 (Wakker, 1999), and, in part as a result of these penalties, estates have switched to non-burning land clearance techniques (Wakker, 1999). Indonesia's fully functional fire detection system would reduce the cost of enforcement by narrowing the area where on-site investigations are needed.

Alternative policy levers that have been suggested to reduce fires on estates are unlikely to be effective. Lengthening estates' leases will not reduce their fire incidence. It has also been suggested that in order to make non-fire clearance technology cheaper, the current ban on the sale of timber from land that has been converted to estates should be lifted (Wakker, 1999).[22] However, such a change would not likely reduce the costs of non-fire methods significantly as many estates have permits to clear-cut timber (Waluyo, 1998) or can obtain them at very low costs (Waluyo, 1998).

Fourth, the total fire incidence on estates may be beyond the socially efficient level, if the total acreage of estates is beyond the socially efficient level. Various subsidies that are given to the estate sector may have led to its over-expansion. Without clear economic justifications, the government provides estates with cheap access to land [the annual per hectare land taxes and license fees are US$0.17 and US$1.78, respectively (Poffenberger, 1996)][23] and until the recent economic crisis, it provided cheap loans for estate expansion and for building processing facilities.[24]

The costs-benefits analysis reveals that even when conservative estimates of the smoke pollution costs are used, the use of fires on estates inflicts net costs on Indonesia and Southeast Asia. These net costs would have been greater if the full long-term health costs could have been

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[22]If estates can sell the timber on the land they clear, they would both profit from the sale of timber and benefit from having to remove less vegetation debris.

[23]Charging a rent of $1 per hectare for lands in Kalimantan that are currently leased to estates would generate $1.1 million per year.

[24] Timber estates receive loans with no interest rate (Ascher, 1993) to cover 32.5% of establishment costs (Potter and Lee, 1999) and subsidies for three years at US$425 per hectare from the Reforestation Fund (Ascher, 1993).

accounted for. The fact that the poor suffer from smoke pollution while wealthier owner of estates benefit from the use of fires, but compensating mechanisms are unavailable, suggests that tolerating the use of fires would be not economically efficient, even if the use of fires had resulted in net benefits.

Logging areas are of concern, as they contain the greatest total number of fire hotspots by virtue of occupying the largest proportion of the surface area. For Kalimantan, where logging firms have almost completely logged their areas, it is too late for the government to discourage the use of flammable logging technologies. However, if logging is to proceed within new logging frontiers, such as Irian Jaya, the government can encourage firms to adopt reduced-impact logging technologies by requiring logging firms to deposit performance bonds that are redeemable if concessions are well-managed.

This study illustrates the power of combining social science and scientific data using GIS and econometric techniques, a method that can be applied to answer many pressing environmental issues. Nevertheless, several interesting questions remain unanswered. Future research question will examine whether or not estates' willingness to inflict smoke pollution costs is influenced by their political connections and their patron's eroding political strength. Data that connect the location of estates with their ownership, should they become available, would permit such research.

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Personal Communication

Dr. C. Bennett, long-term consultant in Indonesia; Dr. M. Cochrane, Michigan State University; Dr. C. Colfer, Center for International Forestry, Bogor; Prof. M. Dove, Yale School of Forestry; Ms. E. Harwell, Yale School of Forestry; Dr. M. Melnyck, Natural Resource Specialist, US Embassy, Jakarta; Prof. J. Romm, University of California at Berkeley; Dr. M. Ross, US Environmental Protection Agency; Dr. A. Setzer, Instituto Nacional de Pesquisas Espaciais, Brazil; Dr. E. Wakker, AID Environment

APPENDIX 1: A simple model of the small and large landholders' choices between fire and non-fire methods for clearing land.

I present a simple model to illustrate that a priori, it is unclear whether large or small landholders are more likely to use fire methods to clear land. The landholder i has a choice of using either (1) the fire method or (2) the non-fire method to clear land of size L_i. If he chooses the non-fire method, fire will not occur on his land but he has to spend an amount E_i in order to clear the land. If he chooses the fire method, he does not have to spend the amount E_i but he faces the risk of fire spreading i.e., there is a probability p that the fire spreads to unintended areas and causes him a loss of F_i. In addition, whether or not fire spreads, the landholder, whose property rights are insecure, faces the risk that his land is appropriated with the probability j_i. If his land is appropriated, he loses F_i. (For simplicity, the loss that results from the spread of fires or from the appropriation of land is assumed to be the same.). The landholder's utility function is $\ln(X_i)$ where X_i is the total wealth and I assume that the total wealth is always positive. The amount of wealth that is exposed to the spread of fire is L_i. The amount of wealth that is not exposed to the spread of fires is W_i. The cost of the non-fire method, E_i, can be expressed as a fraction of the landholder's wealth, where $e_i = \frac{E_i}{W_i}$. The loss when fire spreads or when the land is appropriated, F_i, can also be expressed as a fraction of the landholder's wealth, where $f_i = \frac{Fi}{Wi}$. I assume that $e_i > 0$ and $f_i > 0$.

Section 1. This section illustrates that landholders who have less secure property rights are more likely to use fire methods to clear land. Small landholders' less secure rights make them more likely to choose the fire method, all else equal. If the non-fire method is used, there are two potential payoffs i.e., (1) the payoff if the land is not appropriated and (2) the payoff if the land is appropriated. With probability $1 - j_i$, the payoff is $W_i - E_i$ and with probability j_i, the payoff is $W_i - E_i - F_i$. If the fire method is used, there are two potential payoffs i.e., (1) if fires do not spread and if the land is not appropriated or (2) if either the fire spreads or the land is appropriated or both. With probability $(1-p)(1-j_i)$, the payoff is W_i and with probability $1-(1-p)(1-j_i)$, the payoff is $W_i - F_i$. The landholder compares his expected payoffs from using the fire method to his expected payoffs from using the non-fire method.

The landholder will use the non-fire method, if the following relationship holds:

$$(1-j_i)\ln(W_i-E_i)+j_i\ln(W_i-E_i-F_i)>(1-p)(1-j_i)\ln(W_i)+[1-(1-p)(1-j_i)]\ln(W_i-F_i). \quad (1)$$

To simplify, I substitute $q=(1-p)(1-j_i)$ into (1) and obtain the following:

$(1-j_i)\ln(W_i-E_i)+j_i\ln(W_i-E_i-F_i)>q\ln(W_i)+(1-q)\ln(W_i-F_i)$

$\Longleftrightarrow(W_i-E_i)^{1-j_i}(W_i-E_i-F_i)^{j_i}>W_i^q(W_i-F_i)^{1-q}\Longleftrightarrow W_i(1-e_i)^{1-j_i}(1-e_i-f_i)^{j_i}>W_i(1-f_i)^{1-q}\Leftarrow$

The landholder will use the non-fire method if:

$$(1-e_i)^{1-j_i}(1-e_i-f_i)^{j_i}>(1-f_i)^{1-q}. \quad (2)$$

The following comparative statics exercise examines the effect of less secure property rights on the landholder's choice between the fire method and the non-fire method. In particular, I examine how the proportion of the population of landholders who use the non-fire method would change when property rights become more insecure. I examine the landholder whose e_i is such that he is indifferent to using the fire and the non-fire method at a given j. I call this cutoff level of e_i as e. Holding f_i fixed at f, I examine how the cutoff e changes when j increases. For this landholder who is indifferent between using non-fire and fire methods, the following relationship holds: $(1-e)^{1-j}(1-e-f)^j=(1-f)^{1-q}\Longleftrightarrow$ $(1-j)\ln(1-e)+j\ln(1-e-f)=(1-q)\ln(1-f)$.

I differentiate the previous equation with respect to j, holding $f$constant and obtain:

$-\ln(1-e)+\ln(1-e-f)-\frac{1-j}{1-e}\frac{de}{dj}-\frac{j}{1-e-f}\frac{de}{dj}=(1-p)\ln(1-f)\Longleftrightarrow\frac{de_i}{dj}\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]=$ $-(1-p)\ln(1-f)-\ln(1-e)+\ln(1-e-f)\Longleftrightarrow\frac{de_i}{dj}\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]=-\ln\left[\frac{(1-f)^{1-p}(1-e)}{1-e-f}\right]\Longleftrightarrow$ $\frac{de_i}{dj}\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]=-\ln\left[\frac{(1-f)(1-e)}{1-e-f}\frac{1}{(1-f)^p}\right]\Longleftrightarrow\frac{de_i}{dj}\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]=-\ln\left[\left(\frac{1-e-f}{1-e-f}+\frac{ef}{1-e-f}\right)\cdot\frac{1}{(1-f)^p}\right].$

I now determine the sign of $\frac{de}{dj}$ from the following expression:

$$\frac{de_i}{dj}\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]=-\ln\left[\left(1+\frac{ef}{1-e-f}\right)\cdot\frac{1}{(1-f)^p}\right]. \quad (3)$$

Consider the expression $\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]$. Because j is a probability, and $1-e$ and $1-e-f$ are always positive (by the assumption that wealth is always positive), $\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]\geq 0$.

Consider the expression $\ln\left[1+\frac{ef}{1-e-f}\cdot\frac{1}{(1-f)^p}\right]$. Because $0<f\leq 1$ and $0\leq p\leq 1$, this means that $0<(1-f)^p<1$ and thus $\frac{1}{(1-f)^p}>1$. Because e and f are positive, $1+\frac{ef}{1-e-f}>1$. Thus $\left(1+\frac{ef}{1-e-f}\right)\cdot\frac{1}{(1-f)^p}>1$ and $\ln\left[\left(1+\frac{ef}{1-e-f}\right)\cdot\frac{1}{(1-f)^p}\right]>0$.

Because $\left[\frac{1-j}{1-e}+\frac{j}{1-e-f}\right]\geq 0$ and $\ln\left[\left(1+\frac{ef}{1-e-f}\right)\cdot\frac{1}{(1-f)^p}\right]>0$,

$$\frac{de}{dj}\leq 0. \tag{4}$$

This means that as j increases, the cutoff e for the landholder who is indifferent to using the fire and the non-fire method would decrease. Thus as j increases, the proportion of landholders within the population who use fires to clear land would increase. This analysis reveals that the landholders who have a higher j or equivalently less secure property rights are more likely to use the fire method. Figure 1 illustrates the effect of less secure property rights. The curve shows the distribution of landholders. The vertical line E1 shows the cutoff $e_1$where landholders are indifferent to using the non-fire and fire methods at a given j. Landholders to the right of this vertical line use the fire method while landholders to the left of this line use the non-fire method. The vertical line E2 shows the lower cutoff e_2, which corresponds with the higher j. More landholders in the distribution fall to the right of the vertical line E2 than they do to the right of the vertical line E1. This means that when j increases i.e., property rights are less secure, making landholders more likely to use the fire method.

Section 2. This section illustrates that landholders who have a greater fraction of their wealth exposed to the risk of fires spreading are less likely to use fire methods. Because small landholders have a greater fraction of their wealth exposed to the risk of fires spreading, they are less likely to use the fire method. For this section, I assume property rights are secure and thus $j=0$. In choosing between the fire and non-fire method, the landholder compares the payoff of using the fire method to the payoff of using the non-fire method. His payoff if he uses the non-fire method is (W_i-C_i). His payoff if he uses the fire method is (W_i-F_i), if the fire spreads and W_i, if the fire does not spread.

He chooses not to use the fire method if: $\ln(W_i-E_i)>p\ln(W_i-F_i)+(1-p)\ln W_i \Leftrightarrow W_i-E_i>(W_i-F_i)^p W_i^{1-p}$. I make the following substitutions $f_i=\frac{Fi}{Wi}$. and $e_i=\frac{E_i}{W_i}$. This means that $W_i(1-e_i)>W_i(1-f_i)^p \Longleftrightarrow (1-e_i)>(1-f_i)^p \Longleftrightarrow e_i<1-(1-f_i)^p$.

A landholder chooses the non-fire method if the cost of the non-fire method is relatively low compared to the loss when fires spread, i.e., if the following equation holds:

$$e_i< 1-(1-f_i)^p. \tag{5}$$

Define the fraction of wealth that is exposed to the risk of fires spreading as r_i, where

$r_i = \frac{L_i}{W_i}$. Again, the cost of non-fire land clearance method is E_i. This total non-fire land clearance cost is the non-fire land clearance cost per unit area e multipled by the total land area L. For simplicity, I assume that the land clearance cost per unit area is the same for both large and small landholders and that this cost is constant. This means that $E_i = eL_i \Longleftrightarrow E_i = e\frac{L_i}{W_i}W_i \Longleftrightarrow \frac{E_i}{W_i} = e\frac{L_i}{W_i}$. Substitute in the relationships defined earlier, i.e $e_i = \frac{E_i}{W_i}$ and $r_i = \frac{L_i}{W_i}$. Thus $e_i = er_i$.

Once again, the total loss from fires spreading is F_i. One way to model the loss from fires spreading is to think of the spread of fires as causing a loss of the productivity of the land. (Although the spread of fire may cause damage to other objects of value, this way of modelling the loss from fires allows a simple exposition of the main point made in this section). The productivity of a plot of land of one unit area is one unit and the spread of fires reduces this productivity by the fraction f. So the total loss from fires spreading F_i is the loss per unit area, f, multiplied by the total land area L_i. This means that $F_i = fL_i \Longleftrightarrow F_i = f\frac{L_i}{W_i}W_i \Longleftrightarrow \frac{F_i}{W_i} = f\frac{L_i}{W_i}$. Substitute in the relationships defined earlier, i.e $f_i = \frac{F_i}{W_i}$ and $r_i = \frac{L_i}{W_i}$. Thus $f_i = fr_i$.

Now, I consider Equation 5 that holds for landholders who choose to use the non-fire method and make the subsitutions that $f_i = fr_i$and $e_i = er_i$ and obtain:

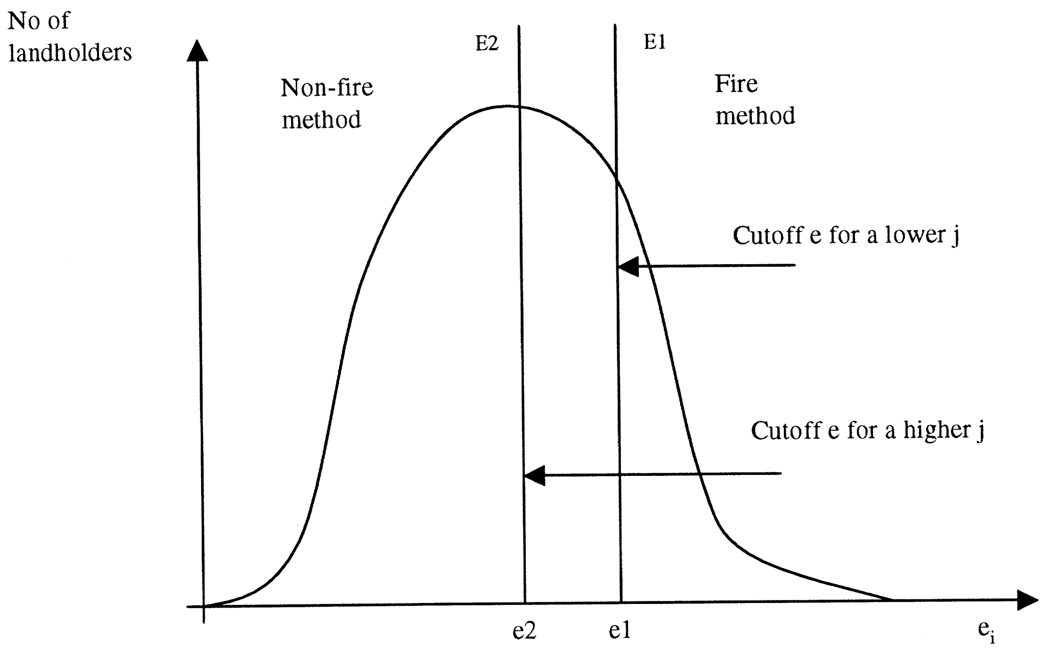
$$er_i < 1 - (1 - fr_i)^p . \tag{6}$$

In Figure 2 illustrates the effect of exposing a greater fraction of the landholders' wealth to the risk of fire spreading. The curve CC represents $er_i = 1 - (1 - fr_i)^p$. The region below this curve represents landholders who use the non-fire method. The region above the curve represents landholders who use the fire method. I fix a particular value for $\frac{e}{f}$. This would be represented by the line G1 which has slope $\frac{e}{f}$. A movement along this line away from the origin represents increasing values of r_i. Landholders who have a greater proportion of wealth exposed to the risk of fires spreading, i.e., they have greater values of r_i, are represented by points on this line that are further from the origin. Comparing the point R1 that is closer to the origin (R1 represents a large landholder) with the point R2 that is further from the origin (R2 represents a small landholder), the point R1 falls in the region of the curve where landholders use the fire-method, while the point R2 falls in the region of the curve where landholders use the non-fire method. This analysis reveals that because small landholders have a large proportion of their wealth exposed to the risk of fires spreading, they are less likely to use a fire method.

Another interesting comparative statics is to examine the effects of an increase in the the non-fire clearance cost relative to the loss from the spread of fires. The line G1 has the slope of $\frac{e1}{f}$ and thus represents the costs of the non-fire method relative to the losses from fire escapes. The line G2 represents an increase in the cost of the non-fire method and thus has a steeper slope of $\frac{e2}{f}$. The cutoff r is the value of r_i for the landholder who is indifferent to using the fire method and the non-fire method. Landholders whose r_i is below the cutoff r use the fire method. When the cost of the non-fire method increases, the cutoff r will increase. This effect can be seen by comparing the point R3 (that represents the r cutoff when the non-fire method is cheaper) to the point R4 (that represents the r cutoff when the non-fire method is more expensive). When the cost of the non-fire method increases, more landholders will be below this cutoff and correspondingly, a larger proportion of the population will use the fire method. This analysis reveals that when the cost of the non-fire method increases, landholders are more likely to use the fire method.

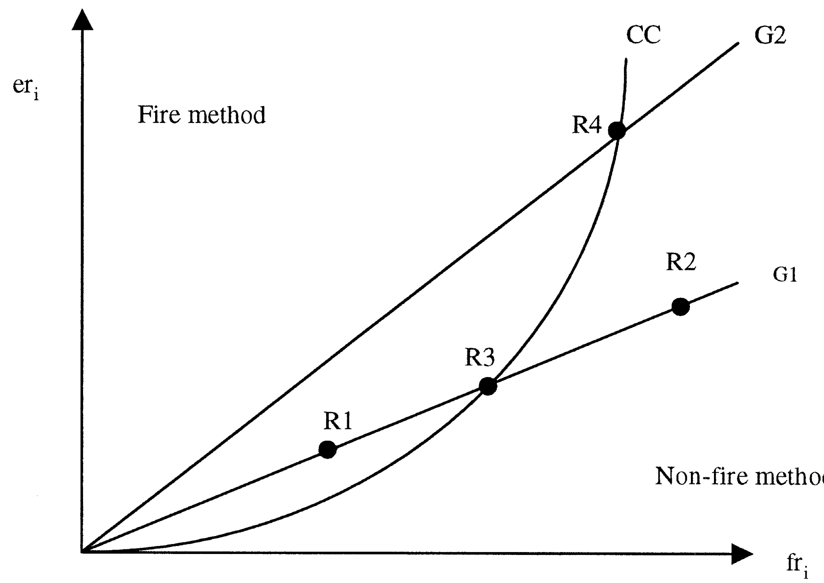
Conclusion. I have illustrated with a simple model that a priori it is unclear whether small or large landholders are more likely to use fire methods to clear land. On the one hand, small landholders' greater fraction of wealth exposed to fires compared to that of large landholders make it less likely for small landholders to use fires. On the other hand, small landholders' less secure property rights compared to those of large landholders make it more likely for small landholders to use fires.

Figure 1. The effect of less secure property rights on the use of the fire method.



The curve shows the distribution of landholders. e_i is the ratio of the cost faced by a landholder of using the non-fire method to his wealth. The cutoff e is the e_i value for the marginal landholder who is indifferent between the fire and the non-fire method. Landholders whose e_i is higher than the cutoff e use the fire method. A higher j represents less secure property rights and leads to a lower cutoff e. Thus less secure property rights makes it more likely for landholders to use the fire method.

Figure 2. The effect on the use of the fire method of the exposure of the landholders' greater proportion of wealth to the risk of fires spreading.



The curve CC shows the marginal landholder who is indifferent between using the fire and the non-fire method. The region above this curve corresponds to the landholders who use the fire method. r_i is the proportion of wealth exposed to the risk of fire spreading. e/f is the ratio of the cost of the non-fire method to the loss from fires spreading. Comparing the points R1 (that represents the large landholder) and R2 (that represents the small landholder) reveals that that large landholders are more likely than small landholders to use the fire-method. Another comparative statics exercise examines the effect of an increase in e/f. The slopes of lines G1and G2 correspond to the smaller and larger values of e/f. The cutoff r is the r_i for the landholder who is indifferent between the use of the fire and the non-fire method. Landholders whose r_i is below the cutoff use the fire method. Comparing points R3 and R4 illustrates that when e/f is high, a higher cutoff r is required for the landholder to be indifferent between the use of the fire and the non-fire methods. This means that when e/f is high, landholders are more likely to use the fire method.

APPENDIX 2: DATA SOURCES

Data	Sources
Fire hotspots (1997)	Forest Fire Prevention & Management Project-Japanese International Cooperation Agency, Indonesia
Fire hotspots (1992)	International Geosphere-Biosphere Project, Italy
Rainfall (1997)	Huffman and Adler, Goddard Space Flight Center, United States
Rainfall (1992)	Janowiak's OLR data, United States
Maps of estates, logging & transmigration areas	Ministry of Forestry, Indonesia
Maps of conservation areas & vegetation types	World Conservation & Monitoring Center, United Kingdom
Maps of elevation roads & rivers	Digital Chart of the World
Soil maps	Food and Agricultural Organization Soil CD, Italy
Maps of sub-districts	Land Planning Agency, Indonesia
Population data & acreage of shifting cultivation	Central Statistical Agency, Indonesia

APPENDIX 3: SMOKE POLLUTION COSTS

A.311 INDONESIA'S HEALTH LOSSES:

Expected annual increased mortality from increased PM10 concentrations

= r /(1+r) * (current mortality rate) * exposed population

where r = (estimated percent effect of PM_{10} per μg/m3) * 0.01

* (the annual mean increase in PM_{10} above a baseline), (WHO, 1999).

the estimated percent effect of PM10 is 0.0705% μg/m3 (M. Ross, EPA, pers. comm; EPA, 1996) and the crude mortality rate in Indonesia between 1990 and 1995 is 7.5 in 1000 (WHO, 1999). Twelve million people in Kalimantan and 4 provinces in Sumatra were exposed to increased PM10 concentrations of 422 $\mu m/m^3$ (WHO, 1999) for 6 months (May-November, 1997). 33 million people in East Java are assumed to have been exposed for 3 months to 211 $\mu m/m^3$ of increased PM10 concentrations.

The value of one life is assumed to be half the foregone lifetime earnings of low-income workers (US$7,804.5). Half the average lifetime earnings are used as some of the deaths are experienced by retired workers. The weekly wage for manufacturing jobs below the supervisory level is Rp. 49,950 (Central Bureau of Statistics, 1997). Workers are assumed to work for 50 weeks per year and for 50 years in total.

An alternative monetary valuation of an Indonesian life is US$35,900 based on the Value of a Statistical Life (VSL). The Indonesian VSL is calculated based on the Taiwanese ratio of annual wages (US$4000 per year) to its VSL (US$461,000) (Liu et al, 1997), adjusted using Indonesia's annual manufacturing wages of US$312. The VSL is calculated using hedonic (quality adjusted) wage regression models, that estimates the wage differential in industries with greater work-related fatalities.[1]

A.312 INDONESIA'S TOURISM LOSSES

It is assumed that the drop in European and American tourists is due to smoke pollution while the drop in Asia Pacific tourists is due to the Asian financial crisis. The welfare losses to Indonesia from a foregone tourist is assumed to be 30% of the average expenditure by a tourist (BAPPENAS, 1999) [Table A.31].

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[1] These ratios, estimated for the early 1980s, are of comparable magnitudes across several countries; The VSL for Japan, Australia and the United States are US$7.6 million, US$3.3 million and US$2.5-US$7.3 million, corresponding to annual wages of US$35,000, US$18,200, US$19400, respectively (Viscusi, 1993).

A.313 INDONESIA'S TRANSPORTATION LOSSES

Net losses from airport closures are assumed to be 20% of their reported gross losses (Indonesia's Directorate General of Air Transportation, cited in Ruitenbeek, 1999).

A. 321 SINGAPORE'S HEALTH LOSSES

The smoke-related excess attendance in public clinics and hospitals for respiratory and eye diseases is the difference in the attendance between August-October 1997 and August-October 1996 (a period with lower smoke levels). Access attendance in private clinics is assumed to be 4 times that in public clinics. [Private clinics serve 80% of the primary health care needs (the Government of Singapore, cited in Hon, 1999)]. The treatment costs per attendance in clinics and hospitals is the lower bound unsubsidized treatment costs in private clinics (US$20). 1% of those seeking medical treatment in public hospitals are assumed to be hospitalized for a one-day at a lower-bound cost of $100 per day (Hon, 1999). Half of those hospitalized are assumed to miss one day of work and thus, lose the lower-bound average salary of S$60 per day (Hon, 1999) [Table A.32].

A.322 SINGAPORE'S TOURISM LOSSES

It is assumed that the fall in tourists from non-ASEAN countries is due to smoke-pollution while the fall in tourists from ASEAN countries and S. Korea is due to the financial crisis. The welfare losses to Singapore from a foregone tourist are assumed to be 30% of the average expenditure by a tourist. The lower-bound estimate of the fall in tourism in the difference between the actual 1996 figures and the actual 1997 figures (S$16.1 million or US$11.5 million). The upper-bound estimate is the difference between the actual 1996 figures and the predicted 1997 figures (S$24.5 million or US$17.5) [Table A.33].

Table 4.1: Size of the clusters of fire hotspots

Size of fire clusters in no. of cells	No. of fire clusters	Size of fire clusters in no. of cells	No. of fire clusters	No. of cells in the East-West direction	No. of cells in the North-South direction
1	4927	74	1	20	9
2	1628	93	1	13	23
3	742	118	1	19	17
4	452	123	1	21	21
5	252	133	1	8	34
6-25	169	136	1	10	28
26-50	576	162	1	16	23
51-73	37	190	1	23	27

Notes: A fire cluster is a group of cells that register the presence of fire hotspots.

Table 5.1: The mean fire hotspots on various land use types in rural Kalimantan in 1992 and 1997

Types of land use ▼	Cells in a given land use in 1997 (1)	Cells with hotspots in 1997 (2)	% of Kal[1] in a given land use (3)	% hotspots found in a given land use (4)	Mean[2] hotspots in 1997 x 100% (5)	Mean hotspots in 1992 x 100% (6)	Change in the mean hotspots (1997-1992) (7)	Relative burning index[3] (8)
Estates	11258	1323	2.6	6.1	11.8	1.4	10.4	8.8
Transmigration	1617	124	.38	.57	7.7	2.2	5.5	3.9
Logging	261279	13050	60.6	60.4	5.0	.75	4.3	2.7
Conservation	36144	774	8.4	3.6	2.1	.54	1.6	0
Smallholdings	120504	6313	28.0	29.2	5.2	1.1	4.1	2.5
Rural Kalimantan	430802	21584			5.0	.85	4.2	2.6

Notes: 1. Kal. is rural Kalimantan. 2. Mean hotspots = the number of cells in a land use type that registers fire hotspots ÷ the sum of cells in that land use type. 3. The relative burning index measures the change in the mean hotspots between 1997 and 1992 in a given land use type, taking that change on conservation areas as a benchmark. Relative burning index = [mean hotspots in a land use in 1997 - mean hotspots in that land use in 1992] - [mean hotspots in conservation areas in 1997 - mean hotspots in conservation areas in 1992].

Table 5.2: Summary statistics for the 1997 data

	Mean	Std Dev
Dependent variable: fire hotspots	.050	.22
Land use variables:		
Dummy for the presence of estates	.026	.16
Dummy for the presence of transmigration areas	.0038	.061
Dummy for the presence of logging areas	.61	.49
Dummy for the presence of small holdings	.27	.45
Dummy for the presence of conservation areas	.083	.28
Density of shifting cultivation (%)	1.8	4.5
Control variables:		
Rainfall (in mm)	490	185
Population density (people per km^2)	22	56
Elevation (in 200m intervals)	170	260
Distance from road (in 2 km intervals)	.20	.23
Distance from river (in 2 km intervals)	.043	.032
Dummy for the presence of peat soils	.074	.26
Vegetation variables:		
Dummy for the presence of montane vegetation	.049	.22
Dummy for the presence of lowland vegetation	.57	.50
Dummy for the presence of swamp vegetation	.11	.32
Dummy for the presence of mangrove vegetation	.014	.12
Dummy for the presence of non-forested areas	.25	.43
Dummy for the presence of unclassified vegetation	.0028	.053
Province dummies:		
Dummy for the province of Kalimantan Barat	.28	.45
Dummy for the province of Kalimantan Tengah	.29	.45
Dummy for the presence of Kalimantan Timur	.37	.48
Dummy for the presence of Kalimantan Selatan	.068	.25

Notes: The land use maps for 1995 are used to represent the 1997 land use. Some of the cells classified as small landholdings could have become estates between 1995 and 1997.

Table 5.3: Cross section estimates for the fire incidence on various landholdings during the 1997 fire season using Ordinary Least Squares (OLS).

Dependent variable: fire hotspots	Coefficient	Std.Error
Land use variables:		
Dummy for the presence of estates	.050**	(.014)
Dummy for the presence of transmigration areas	.0034	(.010)
Dummy for the presence of logging areas	-.0067	(.0077)
Dummy for the presence of smallholdings	-.0037	(.0080)
Density of shifting cultivation (%)	-.000036	(.00064)
Control variables:		
Rainfall (in mm)	-.00010**	(.000030)
Population density (people/km^2)	-.000051**	(.000020)
Elevation (in 200m intervals)	-.000034**	(.0000084)
Distance from road (in 2 km intervals)	-.0019	(.018)
Distance from river (in 2 km intervals)	.18	(.12)
Dummy for the presence of peat soils	.033**	(.015)
Vegetation variables:		
Dummy for the presence of montane vegetation	-.023*	(.010)
Dummy for the presence of lowland vegetation	-.030*	(.0046)
Dummy for the presence of swamp vegetation	.022	(.018)
Dummy for the presence of mangrove vegetation	-.029*	(.016)
Dummy for the presence of non-forested areas	-.0022	(.0082)
Constant is included		
Dummies for provinces are included		
Adjusted R-squared .042		
N. obs. 421095		

Notes: This model examines whether the fire incidence on a land use type exceeds the benchmark of the 'natural' fire incidence, using the fire incidence on conservation areas as the benchmark. Conservation areas are the omitted land use category. The coefficient on a given land use variable estimates the effect of that land use on fire incidence net of the benchmark level of fire incidence. The omitted vegetation dummy is the unclassified vegetation category. Robust standard errors clustered on districts are estimated.
** denotes significance at the .05 level. * denotes significance at the .10 level.

Table 5.4: Linear fixed effects estimates for the 1997 and 1992 fire seasons using OLS.

Dependent variable: fire hotspots	Coeff.	Std. Error.
Dummy for the presence of estates	.040*	(.022)
Dummy for the presence of transmigration	-.021	(.038)
Dummy for the presence of logging areas	-.073	(.052)
Dummy for the presence of smallholdings	-.0075	(.020)
Density of shifting cultivation	.00019	(.00036)
Rainfall	.000045**	(.000017)
Population density	.000050	(.000057)
Year dummy for 1997	.10**	(.027)
Constant included		
No. obs.	861604	
No. groups.	430802	
R-squared	.036	

Notes: This model estimates the effect of a given land use on fire incidence, controlling for time invariant unobservables. Conservation areas are the omitted land use category. The coefficient on a given land use variable estimates the effect of the land use on fire incidence, net of the fire incidence on conservation areas. Standard errors clustered on districts are reported.

** denotes significance at the .05 level. * denotes significance at the .10 level.

Table 5.5: Mean hotspots on various landholdings in 1992 and 1997

Land use type in 1992 ▶ / in 1997 ▼	Conservation (1)	Estates (2)	Transmigration (3)	Logging (4)	Smallholdings (5)
Conservation (1)	n 36144 1997 .021 1992 .005	n 0	n 0	n 0	n 0
Estates (2)	n 141 1997 .13 1992 .007 c .107	n 6514 1997 .10 1992 .014	n †	n 2446 1997 .17 1992 .02 c .107	n 2144 1997 .10 1992 .014 c .045
Transmigration (3)	n †	n 0	n 1067 1997 .078 1992 .022	n 262 1997 .080 1992 .019 c .018	n 205 1997 .098 1992 .0049 c .052
Logging (4)	n 0	n 0	n 0	n 261279 1997 .050 1992 .007	n 0
Smallholdings (5)	n 0	n 0	n 0	n 0	n 120504 1997 .052 1992 .011

Notes: n = no. of cells. 1997 = mean hotspots in 1997. 1992 = mean hotspots in 1992. † = too few observations. c = the net change in the mean hotspots between 1992 and 1997 for cells that switch into estates from a given land use type, using that net change for cells that remained in that land use as a benchmark. For example, the net change in fire incidence when cells switch from conservation areas into estates is given by: [mean hotspots in 1997 - mean hotspots in 1992] (for cells that switched from conservation areas in 1992 into estates by 1997) - [mean hotspots in 1997 - mean hotspots in 1992] (for cells that remained in conservation areas in 1997) = [.13 - .007] - [.021 - .005] = .107. (See column 1, row 2 and column 1, row 1.)

Table 5.6: Cross section estimates of fire incidence on older and 'more recent' estates during the 1997 fire season using OLS.

Dependent variable: fire hotspots	Coeff.	Std.Error
Land use variables:		
Dummy for the presence of 'more recent' estates	.067**	(.029)
Dummy for the presence of older estates	.038**	(.011)
Dummy for the presence of 'more recent' transmigration areas	.0044	(.011)
Dummy for the presence of older transmigration areas	.00074	(.016)
Dummy for the presence of logging areas	-.0068	(.0077)
Dummy for the presence of small landholdings	-.0038	(.0080)
Density of shifting cultivation (%)	-.000026	(.00064)
Adjusted R-squared .04		
N. obs. 421095		

Notes: 'Older' estates are those with leases granted before 1992. 'More recent' estates are those with leases granted after 1992. 'Older' and 'more recent' transmigration sites are defined analogously. The omitted land use category is the dummy for conservation areas. The coefficient for a given land use variable estimates the effect of that land use on fire incidence, net of the fire incidence on conservation areas. Other variables as in the original cross-section are included. Robust standard errors clustered on districts are reported.

** denotes significance at the .05 level. * denotes significance at the .10 level.

Table 5.7: Comparison of the descriptive statistics of the estates and the conservation areas in the neighbor model for the 1997 fire season.

	Estates (1)		Conservation Areas (2)	
	Mean	Std. Error	Mean	Std. Error
Fire hotspots	0.12	0.0042	0.063	0.0028
Rainfall	334	1.53	325	1.16
Population density	28	0.52	35	0.36
Elevation	42	1.09	53	1.1
Dummy for the presence of peat soil	0	0	0.012	0.0013
Distance from roads	0.096	0.001	0.1	0.00087
Distance from rivers	0.046	0.00038	0.43	0.00031
Dummy for the presence of montane vegetation	0.00048	0.00028	0.00013	0.00014
Dummy for the presence of lowland vegetation	0.66	0.0061	0.57	0.0058
Dummy for the presence of mangrove vegetation	0.026	0.002	0.073	0.0003
Dummy for the presence of swamp vegetation	0.016	0.0016	0.073	0.003
Dummy for the presence of non-forested areas	0.03	0.0058	0.028	0.0052
Dummy for the presence of unclassified vegetation	0.00048	0.00028	0	0
No obs.	6278		7424	

Notes: The neighbor model compares estates with nearby conservation areas to control for land quality.

Comparison of estates and conservation areas	**Estates**	**Conservation Areas**
Σ Coefficient$_i$ X Mean$_i$ (i = 1 to the sum of included variables) All variables except neighborhood dummies and land use dummies are included.	-0.039	-0.038

Table 5.8: Neighbor estimates for the effects of estates on fire incidence during the 1997 fire season using OLS

		Coefficient	Std.Error
Dependent variable: fire hotspots			
Dummy for the presence of estates		.058**	(.014)
Adjusted R-squared	.048		
N. obs.	13702		

Notes: This model estimates the effect of estates on fire incidence, using the fire incidence on nearby conservation areas as a benchmark. Conservation areas is the omitted land use category. The coefficient on the estate variable estimates the effect of estates on fire incidence net of the benchmark level of fire incidence on conservation areas. The mean hotspots on conservation areas in the neighbor model is .063. Other control variables are as in the original cross-section model. There are 20 neighborhood dummies included in the model to correspond with the 21 neighborhoods (i.e. areas that contain neighboring estates and conservation areas). Conley's spatial error corrected standard errors using cutoffs of 50 cells in the longitude and latitude directions are reported. The standard errors remain similar when cutoffs of 100 and 300 cells are used. ** denotes significance at the .05 level.

Table 6.1: OLS estimates of the effects on fire incidence of the September 1997 government announcement that the use of fires was banned and that enforcement efforts would be stepped up

Dependent variable: fire hotspots

	Coeff	Std.Error
Ban	-.0024	(.0044)
Land use variables interacted with the ban variable:		
Dummy for the presence of estates*ban	.0032	(.0090)
Dummy for the presence of transmigration areas*ban	-.015	(.013)
Dummy for the presence of logging areas*ban	.0033	(.0047)
Dummy for the presence of small landholdings*ban	-.0029	(.0071)
Density of shifting cultivation*ban	-.00018	(.00043)
Land use variables not interacted with the ban variable:		
Dummy for the presence of estates	.026**	(.0086)
Dummy for the presence of transmigration areas	-.00066	(.010)
Dummy for the presence of logging areas	-.0095**	(.0039)
Dummy for the presence of small landholdings	-.0049	(.0057)
Omitted category: dummy for the presence of conservation areas		
Density of shifting cultivation (%)	-.00018	(.00043)
Adjusted R-squared .022		
N. obs. 850632		

Notes: To examine the effect of the ban on fire incidence, the periods before (08/01/97) and after the ban (9/10/97) are compared. To extract the ban's effect on fire incidence on estates, I I subtract (a) the difference in the fire incidence on conservation areas before and after the ban (that is due to natural variation, e.g. weather) from (b) the difference in the fire incidence on estates before and after the ban (that is due both to the ban and natural variation). The ban variable takes the value 0 for the period before the ban and 1 for the period after. The omitted dummies are the dummy for conservation areas and the product of the dummy for conservation areas and the ban dummy. The coefficient on the ban variable indicates the increase in fire incidence on conservation areas after the ban. The coefficient on the product of the ban variable and the estates dummy indicates the increase in fire incidence on estates after the ban, using the difference in fire incidence on conservation areas before and after the ban as a benchmark. If the ban reduced the fire incidence on estates, this coefficient would be negative. Other control variables as in the original cross section model are included. Robust standard errors clustered in districts are reported.

Table 6.2: OLS estimates of the fire incidence on estates in rural areas with high population density during the 1997 fire season

	Coeff	Std.Error
Land use dummies interacted with the dummy for high population density:		
Dummy for the presence of estates*dummy for high population density	.014	(.019)
Dummy for the presence of transmigration areas*dummy for high pop. density	-.016	(.020)
Dummy for the presence of logging areas*dummy for high population density	.022	(.014)
Dummy for the presence of small landholdings*dummy high population density	.0031	(.017)
Density of shifting cultivation*dummy for high population density	.0012	(.0011)
Dummy for high population density	-.012	(.014)
Land use variables:		
Dummy for the presence of estates	.046*	(.021)
Dummy for the presence of transmigration areas	.021	(.020)
Dummy for the presence of logging areas	-.013	(.0078)
Dummy for the presence of small landholdings	-.00071	(.011)
Density of shifting cultivation	-.00091	(.00097)
Adjusted R-squared .040		
N. obs. 421095		

Notes: The dummy for high population density areas takes the value 1 for rural areas with above average pollution densities and 0 otherwise. The omitted dummies are the dummy for conservation areas and the product of the dummy for conservation areas and the dummy for high population density areas. The coefficient of the product of the estate and the dummy for high population density areas estimates the additional fire incidence on estates in high population density areas. If estates in high population density areas have a lower fire incidence than those in low population density areas, this coefficient would be negative. Other variables are as in the original cross-section model. Robust standard errors clustered on districts are reported.

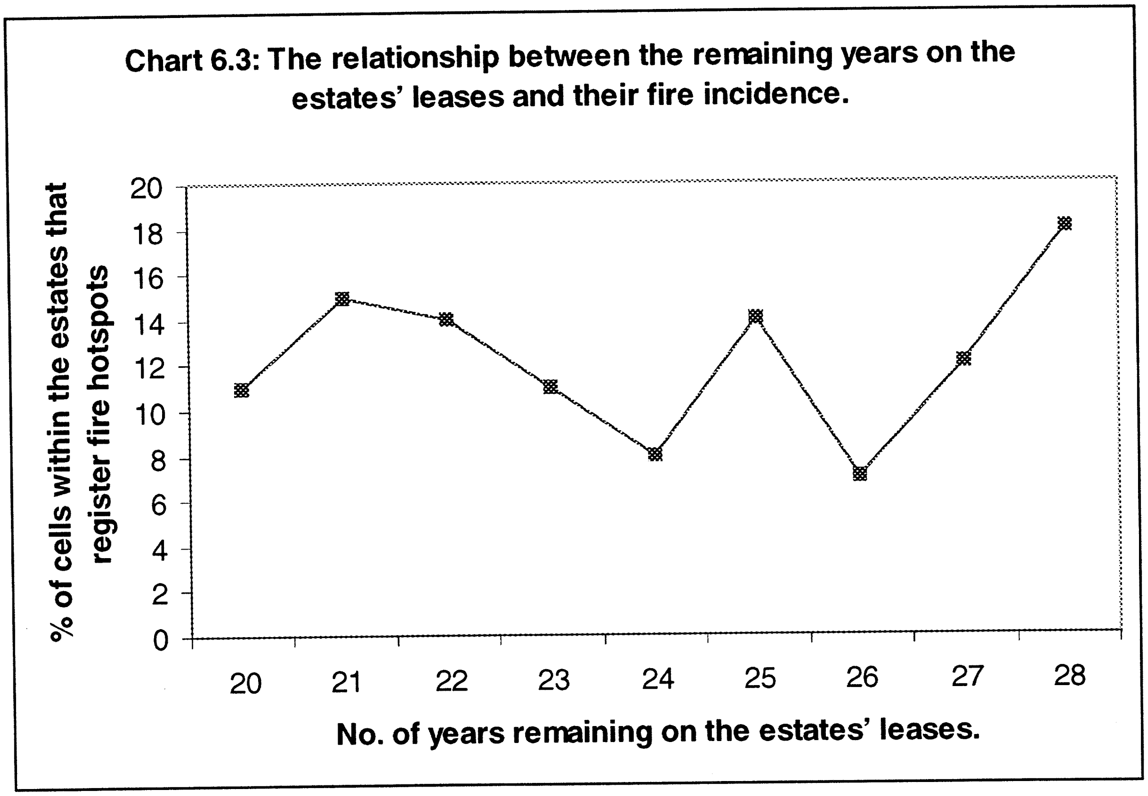
Chart 6.3: The relationship between the remaining years on the estates' leases and their fire incidence.
% of cells within the estates that register fire hotspots
0
2
4
6
8
10
12
14
16
18
20
20
21
22
23
24
25
26
27
28
No. of years remaining on the estates' leases.

Table 7.1: Estimates of savings from the use of fires for land clearance per hectare of estate cleared

		Cost in thousands of Rp. per hectare cleared			Min. savings from burning in thousands of Rp.	Min. savings from burning in US$
▼ Land type	Clearing ► technique	Felling stacking and burning	No burning with some use of machinery	Mechanical clearing		
Forested land	Lower-bound	430	550		100	12.5
	Upper-bound	450	700	1,025	270	33.8
Grassland	Lower-bound	400	525		125	15.6
	Upper-bound	420	550	575	150	18.8

Source: Kuruvilla and Mohandas, agronomists at Agro Hope Ltd., an oil palm company, estimated the land clearance costs for oil palm estates in Central Kalimantan in 1997 (from Erik Wakker, pers. comm.).
BAPPENAS (1999) estimates the savings from the use of fires at Rp. 330,000 or US$41.25 per hectare.

Table 7.2: Estimated losses from fire-related smoke pollution and carbon dioxide release in 1997

	Losses in US$ million				
Assumptions ▶	Health is measured by foregone wages		Health is measured by the Value of Statistical Life		
					Costs of carbon dioxide emissions are included.
Costs are borne by ▶	Indonesia	Indonesia & Singapore	Indonesia	Indonesia & Singapore	Indonesia, Singapore & rest of the world
	(1)	(2)	(3)	(4)	(5)
▼ Types of losses					
Foregone foreign tourism	9.4	20.9	9.4	20.9	20.9
Transportation disruption	0.048	0.048	0.048	0.048	0.048
Health	143.1	143.46	658	658.36	658.36
Carbon dioxide emissions	-	-	-	-	350
Losses resulting from all biomass burning in Sumatra and Kalimantan	153	164.4	667.4	679.3	1029.3
Losses from estates in Kalimantan[3]	3.9	4.2	17	17.3	26

Notes.

1. Details of the calculations are in Appendix 3.

2. The exchange rates used are Rp. 8000=US$1 and S$1.5=US$1.

3. I assume that Kalimantan contributes half the total smoke pollution losses to Indonesia and Singapore. The estates' contribution to smoke pollution losses (5.1%) is given by the product of percentage of land cover occupied by estates (2.6%) and its flammability factor (2) as a fraction of the total contribution of land fires to smoke pollution losses [2.6*2 ÷ (2.6%*2 + 97.3%* 1)].

4. Indonesia: The increased mortality due to exposure to smoke concentrations in Kalimantan and parts of Sumatra and Java (18,330) is calculated using the WHO (1999) technique that relates increased mortality with the effect of increased concentrations of PM10 (particulate matter with a diameter of 10 μm. of less). The increased mortality is then valued in money terms by using (1) half the foregone lifetime earnings of a worker under supervisory level in the manufacturing sector (US$7,804.5) or (2) the Value of a Statistical Life (VSL) for Indonesia (US$35,900). The foregone net earnings in foreign tourism amount to 30% of the foregone tourism revenue that resulted from the drop in American and European tourists between the projected 1997 figures

(based on the 1991-6 trend) and the actual 1997 figures. Transportation disruption is 20% of the gross losses of airports that had to close due to the smoke.

5. Singapore: The foregone net earnings in foreign tourism equals to 30% of the foregone tourism revenue that resulted from the drop in non-ASEAN [Association for Southeast Asian Nations] tourists (South Korea is also excluded) between the 1996 figures and the actual 1997 figures. This estimate is lower (by US$6 million) than the estimate using the difference between the Singapore Tourism Board's projected 1997 figures and the actual 1997 figures. Only short-term health treatment costs are included.

6. Global: The gross carbon dioxide emission from biomass burning in Sumatra and Kalimantan (calculated using burn scar maps for selected areas) is 700 million tonnes (Levine, 2000). The 'greenhouse' cost from fires is the emissions of carbon dioxide net of that sequestered by regrowth. These net emissions are assumed to be half the gross amount. The monetary cost of carbon dioxide of US$10 per tonne is based on the estimated costs for low-cost abatement opportunities in developing countries (Austin and Faeth, 2000). Ideally, the cost-benefit of the use of fires on estates would compare the additional carbon released by the fire versus the non-fire land clearance methods. Fire methods releases additional carbon by burning soil organic matter (SOM) that is abundant in peat soil (and less sandy soils) and by causing soil erosion-induced nutrient losses that reduce plants' ability to sequester carbon (Wirawan, 1993). However, figures are not readily available for such comparisons.

7. Figures for the losses to Malaysia, Brunei and Southern Thailand are not available.

Table 7.3: Estimated costs from fire-related smoke pollution and carbon dioxide release (per hectare of estate that burned)

	Losses in US$ per hectare of estate that burned.				
Assumptions ▶	Health is measured by foregone wages.		Health is measured by the Value of Statistical Life.		Costs of carbon dioxide emissions are included.
Costs are borne by ▶	Indonesia	Indonesia & Singapore	Indonesia	Indonesia & Singapore	Indonesia, Singapore & the rest of the world
	(1)	(2)	(3)	(4)	(5)
▼ Assumptions on the % of the land within a 1.1 km^2 cell that burned.					
100%	26.8	28.9	116.8	118.9	178.7
80%	33.5	36.1	146	148.6	223.4
60%	44.7	48.1	194.7	198.2	297.8

Notes: 1323 estate cells register hotspots. The losses per hectare of estate burned are estimated under various assumptions of how much area had burned within a cell for those cells that register the presence of fire hotspots. A range of assumptions is used because AVHRR data does not provide this information.

Table 7.4: Comparison of the costs and benefits from the use of fires on estates in US $ (per hectare of estate that burned).

	Benefits in US$	Losses in US$				
		Health is measured by foregone wages		Health is measured by by the Value of Statistical Life		Carbon dioxide emissions are included
Benefits received by ► or costs borne by	Estates	Indonesia	Indonesia & Singapore	Indonesia	Indonesia & Singapore	Indonesia, Singapore & the rest of the world
	(1)	(2)	(3)	(4)	(5)	(6)
Upper-bound estimates	12.5	26.8	28.9	116.8	118.9	178.7
Lower-bound estimates	41.3	44.7	48.1	194.7	198.2	297.8

Table A.31: Indonesia's foregone earnings from tourism in 1997 in US$

	Total no. of tourists (in thousands)								Average tourist's spending in 1991-7 in US$	Total tourist spending in 1997 foregone in thousands of US$
	Years						Expected in 1997 based on 1991-6 trends	Actual in 1997		
▼ Region of origin	1991	1992	1993	1994	1995	1996				
Americas	129	158	190	212	201	244	246	209	1,445	53,465
Europe	482	562	660	799	794	754	854	820	1,270	43,180

Source: Figures on the total number of tourists and their average expenditure are from the Dept. of Tourism, cited in BAPPENAS (1999). BAPPENAS (1999) fitted a trend curve based on the 1991-1996 figures and predicted the expected number of tourists in 1997. The exchange rate used in the table is Rp. 2500 = US $1. These figures were then converted at the rate of Rp. 8000 = US$1.

Table A.32: Excess attendance at Singapore's public clinics and hospitals during the 1997 fire season

▼ Main complaint	Public hospitals: Attendance in Aug-Oct 1996	Public hospitals: Attendance in Aug-Oct 1997	Public hospitals: "Excess" attendance in 1997	▼ Main complaint	Public polyclinics: Attendance in Aug-Oct 1996	Public polyclinics: Attendance in Aug-Oct 1997	Public polyclinics: "Excess" attendance in 1997
Asthma, bronchitis, emphysema	1,989	6,225	4,236	Conjuctivitis	4,395	5,233	[838]
Pneumonia	858	2,210	1,352	URTI	116,136	115,738	398
Acute conjuctivitis	273	709	436	Allerguc rhinitis	1,696	1,421	274
Ischeamic heart diseases	780	2,180	1,400	Acute bronchitis	1,456	737	719
				Asthma	12,126	10,184	1,942
				Enzema	9,186	8,220	966
Total			7,424	Total			3,461

Notes: Attendance figures from Singapore's Ministry of Health, reported in Hon (1999).

Table A.33: Singapore's foregone revenue from the drop in non-ASEAN tourists and non-S. Korean tourists

	No. of Tourist Arrivals			Foregone earnings in S$(thousands)	
Months	1996	Actual in 1997	Predicted in 1997	Actual in 1996 minus actual in 1997	Predicted in 1997 minus actual in 1997
August	436,772	432,254	452,059	3,027	13,269
September	364,481	368,026	377,238	[-2375]	6,172
October	394,623	315,391	408,435	53,085	62,339
Total				53,737	81,780

ESSAY 2

THE ROLE OF EDUCATION AND EXPENDITURE SHOCKS IN FOREST CLEARANCE:

EMPIRICAL EVIDENCE FROM INDIGENOUS HOUSEHOLDS IN BOLIVIA'S PROTECTED AREAS

Abstract

Many conservation areas have been designated within indigenous territories. This study examines whether education can potentially reduce households' agricultural-related forest clearance by increasing the returns to wage labor. It analyzes a unique survey of 649 indigenous households in protected areas in Bolivia's lowland forests. It finds that an additional year of education among household heads is associated with a reduction of 0.05 hectares or 4.3% of the annual mean household forest clearance, increased returns of 2.6% in wage labor and a 21% increase in days worked in wage labor. Thus, the 3-year average increase in education among the youngest cohorts is associated with potentially significant reduction in forest clearance in the study site. Expenditure shocks, however, are associated with a 39% increase in the mean annual household forest clearance. These associations, though insufficient at present to establish causality, provide some preliminary evidence for the potential role of education and mechanisms to cope with expenditure shocks in reducing households' forest clearance.

1 INTRODUCTION

Tropical deforestation proceeds unabated. Developing countries lost 13.7 million hectares of forests per year between 1990 and 1995, a rate comparable to the 15.5 million hectares lost per year between 1980 and 1990[1] (WRI, 2000). These annual losses are enormous, amounting to an area the size of Nicaragua. In an effort to avert deforestation, governments in developing countries, with the support of international environment and development organizations, have designated conservation sites in large forested areas (Kramer et. al., 1997). However, many of these conservation areas have been designated on indigenous[2] territories that are inhabited by local communities. For example, in Central America, 85% of the total area under protected status[3] (Herlily, 1997) or 10.5% of the forested areas (WRI-UNDP-UNEP-WB, 1998) overlap with 75 cultural parks (Herlily, 1997). Households in these communities contribute to deforestation by converting forests into their agricultural fields. As these households do not take into consideration the external benefits from forests such as global biodiversity protection and watershed protection for other communities, it is useful to find policy levers that can reduce their deforestation.

This study examines whether education can reduce household forest clearance by increasing the returns to wage labor and whether expenditure shocks increase household forest clearance. It analyses a dataset of 649 indigenous households from 59 villages in Bolivia's indigenous territories that overlap with protected areas. Despite its limited number of variables, the pilot survey used is unique as most standard household surveys in developing countries exclude these isolated communities. By comparing households within the same villages and controlling for other household characteristics, this study examines whether more education among household heads is associated with less agriculture-related household forest clearance and the household heads' higher wages and their greater participation in wage employment; and whether expenditure shocks are associated with greater household forest clearance. The finding of such associations would provide some preliminary evidence for the potential role for education

[1] These figures understate the level of forest degradation, as they exclude forest degradation due to logging (WRI, 2000).

[2] In Latin America, indigenous peoples include the descendents of peoples who originally inhabited the continent, but who had been pushed towards marginal areas by European migrants and the descendents of African migrants to Latin America who self-identify as indigenous peoples. Although historically these communities are characterized by their weak political and economic status, they have increased their political organization, particularly in the 1980s and 1990s.

[3] These areas include the Tawahka Asangi Biosphere Reserve in Tawahka territory in Honduras, the Rio Plantano Biosphere Reserve in Miskito, Garifuna and Pech territories in Nicaragua and the La Amistad Biosphere Reserve in the Cabecar and Bribri territories in Costa Rica (Herlily, 1997).

and consumption smoothing mechanisms in conservation efforts, though further work would be needed to make causal inferences.

If the households surveyed continue their current rates of forest clearance for the next 10 years, forest cover in the study site would be reduced significantly by 10%. Such a large decrease in forest cover would substantially reduce the benefits of watershed protection to the surrounding communities and contribute to the reduction in global biodiversity. Despite these losses from deforestation, the potential of policy tools such as education in reducing deforestation remains unclear. Previous studies that correlated households' education and expenditure shocks with forest clearance, though innovative (Godoy et al., 1998a; Godoy et al., 1998b), may find spurious correlations as they used only a single variable (i.e. the distance of villages to town) to control for the inter-village differences.[4] A priori, the influence of education is ambiguous, as it may lead to greater returns from family farming and thus encourage forest clearing, or it may lead to greater increases in wages and thus encourage participation in wage labor. Similarly, the effect of expenditure shocks on agricultural expansion and thus forest clearance is unclear, as households may rely on alternative mechanisms to cope with such shocks.

The potential role of education as a tool for conservation in Latin America is of interest, as governments there have increased investments in rural education since the 1990s (Wolff et al, 1994). Bolivia's education reform project has expanded educational opportunities to its indigenous population (World Bank, 1996) and provides bilingual education (Albo, 1994). Policy levers that reduce household forest clearance will assist the current approach in conservation, including that of the Global Environment Fund in Bolivia's protected areas, that aims to address both the needs of the local inhabitants and the goals of conservation (World Bank, 1998). Rightly, the previous schemes of enclosing conservation sites and expelling their inhabitants have been abandoned (Wells et al., 1992). Nevertheless, as many conservation benefits are external to the local community, policy levers that alter the incentives of these people are needed to make their actions more compatible with conservation goals.

Indigenous communities' ability to achieve conservation goals, while improving their income levels, is also important for their survival. The potential to attain conservation goals has been one important motive behind the national governments', international environmental

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[4]Villages that are closer to the town tend to have greater educational opportunities, as well as greater supply of wage labor and greater scarcity of old-growth forests.

groups' and donor groups' support for territorial protection for indigenous groups (Conklin and Graham, 1995; Brysk, 1994; Turner, 1995). Although the failure to achieve some level of conservation will reduce such support to the detriment of indigenous peoples (Conklin and Graham, 1995), it is unlikely that households' forest clearance decisions fully take into account this wider political externality from conservation.

The remainder of this paper is organized as follows. Section 2 describes the study sites and households; Section 3 describes the data; Section 4 outlines the empirical methods; Section 5 reports the analysis and the results of the role of education and expenditure shocks; Section 6 compares the costs and benefits of increased educational opportunities; and Section 7 draws conclusions.

2. THE VILLAGES AND HOUSEHOLDS AND THEIR FOREST CLEARANCE

The study sites are (1) the Territorio Uno along the Rio Maniqui close to the Beni Biosphere Reserve), (2) the Isiboro-Secure National Park and (3) the Lomerio area. The first two sites are in the Beni Department, while the third site is in the neighboring Santa Cruz Department, in the Bolivian lowland forest area. The indigenous groups who live there are the Chiquitanos, Tsimanes, Mojenas and Yuracares in their respective villages (Piland, 1991; McDaniel, 2000; Huanca, 2000). Villages differ in key characteristics that would influence households' forest clearance and participation in wage labor.

Both old-growth and secondary forests in the study sites provide positive environmental externality. Old-growth forests have greater biodiversity value. Secondary forests that have been cleared fairly recently for agriculture but left to regenerate for a minimum of 3-4 years (Valdez, pers. comm.) also provide ecological services. Older secondary forests protect the watershed, thus providing benefits to communities beyond the particular village where forests are cleared.

Villagers do not need to seek the permission of members of their community to clear forests for agriculture. Any villager can clear the old-growth forests in their villages and he can clear secondary forests after receiving routine permission from the previous farmer on that land (Piland, 1991). Households clear forests annually for fields to plant their main crops of rice and corn. In the following year, households leave these older fields fallow (or plant them with secondary crops) and clear more forests for new fields. In choosing to clear old-growth or secondary forests, household heads trade-off the additional work required to clear old-growth forests with the subsequent lower weeding requirements on these fields (Piland, 1991).

It is the male head who determines the amount of his household's forest clearance, as a result of the households' structure and labor division. Most households in these communities (75%) are generally nuclear male-headed households, with the male head providing the main source of male labor in the household, and no other adult males making significant labor contribution to the household.[5] Only 18% of households have 2 male adults while 5% have three. Young adult men (16 years and above) marry early and move out of their parents' house within 2-3 years to form their own households.

As most of the households rely on male head as the main provider of labor in the household farm, his allocation of time to work on the household farm is the limiting factor on the amount of forest his household can clear. He undertakes the main tasks in forest clearance, such as cutting the large trunks and branches, while his spouse and children assist only in the subsequent, less strenuous tasks. Even in the event of labor sharing among households, the male head's contribution of labor to other households determines how much labor the household receives in return. Households in general do not hire outside labor on their farms (Huanca, pers. comm.).

The male head decides the allocation of his work hours between (1) his own farm and (2) wage labor. He faces a trade-off between these two activities as they demand labor in the same period. The dry season is the time when wage employment opportunities are most abundant, including employment from non-indigenous ranchers, loggers and farmers, the main employers of wage laborers. However, the dry season is also the time during which he must clear forest to prepare agricultural fields, if he wishes to conduct his own family farming. The decision to devote substantial time to wage labor in the dry season would reduce the time he has to clear forests. In contrast to men, women do not work in wage labor. After performing their tasks on the household farm, women allocate any additional time to other work such as cultivating home gardens and making mats for sale (Huanca, pers. comm.).

[5] These survey figures are compatible with the Census figures that 77% of the indigenous households in the Bolivian lowland are nuclear (Censo Indigena, 1996).

In allocating his work hours to his own farm or to wage labor, the male-head compares the net returns to his own agricultural relative to those from wage labor. His education can potentially influence these relative net returns. A priori, the increase in education could lead to ambiguous effects. First, education may raise returns from family farms (Lockheed et al, 1990) and lead to greater forest clearance.[6] Households heads with greater education can obtain greater returns from the sale of their agricultural product at the same market price, as they can avoid being cheated (Huanca, pers. comm.). [7] Second, education may raise wages from outside employment, and thus the opportunity costs of one's own agriculture or the opportunity costs of forest clearance. The net effect of education would depend on which of these influences dominates. If the latter dominates, then education should be associated negatively with forest clearance, positively with wages and positively with participation in wage labor.

Whether education encourages households to shift into alternative employment is an important policy question, even though most of the current alternative employment opportunities involve forest clearing. Only work with the church, non-government organizations (NGOs) and the one existing sustainable forestry project is environmentally benign. A positive finding would suggest that education, along with policies that improve the supply of environmentally benign employment (e.g., the encouragement of sustainable logging activities or sustainable intensified agriculture) could reduce forest clearance.

Another question of interest is whether households clear more forest when they are hit by an expenditure shock. Although the use of common property resources as a 'social safety net' has been documented for some communities in arid areas (Jodha, 1992), a priori, it is unclear that these forests do provide such a service because these communities may have alternative mechanisms to cope with such expenditure shocks, such as savings, loans, transfers (Townsend, 1995), or wage employment (Kochar, 1999). According to field researchers at the study sites, however, several of these mechanisms do not operate in these communities. These households have little savings, and even though there are some limited transfers, households bear the burden of the expenditure shocks from the deaths and illnesses of their household members (Huanca, pers. comm.).

[6]Agricultural intensification is less likely in these study sites due to scarcity of agricultural extension services, pesticides and herbicides.
[7]The ability of the more educated to negotiate for greater net return from sales has also been observed in other farming communities (Jamison and Lau, 1982).

To measure whether the household experiences an expenditure shock, the occurrence of at least one death of a household member is used. Funeral-related expenses are costly because the alcohol that is necessary in the funeral ceremony is purchased at high prices from whichever trader is visiting the village at the time of death (Huanca, pers. comm.). As most of these deaths occur prior to the agricultural year, household heads can respond to deaths by increasing forest clearance for agriculture or increasing participation in wage labor.[8] Two alternative measures for the shock are described in section 4.

3. DATA DESCRIPTION

The cross-section survey data include 649 households from 59 villages, spread fairly evenly in the 3 study sites (Table 1). Anthropology students, trained in survey techniques and familiar with the study sites, collected the data. They stratified the sampling of villages to ensure the collection of data both from villages that are close to the town and villages that are isolated. Within each village, they randomly sampled an average of 10 households or an average of 43.9% of the households in the surveyed villages. In total, the survey sampled about 5.2% of the indigenous households in the Bolivian lowlands (Table 2). Almost every household (98%) selected to be interviewed participated (Huanca, pers. comm.). Household members are those who contribute to the production or consumption in the household.

Two study sites were surveyed for the 1997-8 agricultural year and one site was surveyed for the 1996-7 agricultural year. The forest clearance in the years surveyed are likely to capture the average annual forest clearance, as those years and the preceding year were not exceptionally dry or wet, factors that could have influenced the amount of forest clearance. To account for differences in the study sites, as well as the different agricultural years surveyed, the regression model includes a dummy variable for each of the study site.

The amount of forest cleared and the distinction between secondary forests and old-growth forests are based on the respondents' judgments, as their judgments have been found to be fairly reliable. Respondents' estimates of the amount of forest cleared have been fairly consistent with actual field measurements made by the interviewers (Godoy et al, 1998c). Household heads

[8] The survey asks about deaths 9 months prior to and during the period when households can still clear additional forests or work additional days in wage labor to respond to the shock. There is some measurement error because deaths that occurred 3 months after the end of the forest clearance season were inadvertently included in the survey question.

from the same village generally agreed on whether a particular forest patch was old-growth or secondary forests, even though the distinction between old secondary forest and old-growth forest is difficult to make (Valdez, pers. comm.). As this study compares forest clearance among households within the same village, the systematic variation across villages in the judgement of old-growth and secondary forests would not bias the results.

The mean annual old-growth forest clearance of 0.56 hectares per household translates into a significant amount of total forest clearance. For example, the 850 households in the Lomerio area would clear 476 hectares per year or 4760 hectares every 10 years, amounting to 10% of the total available old-growth forests for agriculture and sustainable forestry (extrapolation from McDaniel, 2000). This significant reduction in the amount of old-growth forest area would threaten the ecological sustainability of the Lomerio 'green' logging project, a project that relies on long cycles for re-cuts, and would thus require expansive forest areas. This deforestation will also threaten the protection of the watershed. The mean annual clearance of both old-growth and secondary forests of 1.17 hectares would translate into an even larger amount of total forest cleared.

The mean education of a male household head is 2.9 years, a figure that is lower than the Bolivian average of 4.4 years (World Bank, 1995). The improvement in the educational attainment of the successive cohorts of male household heads has been limited. Comparing household heads within the same village with comparable fathers' education reveals the youngest cohort (17-29 years old) has 3.1 more years of education than the oldest cohort (61-80 years old) whose mean education is close to zero. The second youngest cohort (30-44 years old) and the third youngest cohort (45-60 years old) have only 2.3 and 0.5 more years of education compared to the oldest. These figures are not likely to understate the improvement in educational attainment, because the out-migration levels of educated persons have been low (McDaniel, pers.comm.).

The supply of educational opportunities in these villages is limited. 16% of the villages surveyed do not have any village schools while 23% of the villages have schools with maximum grades below the primary grade level. Even in the 33% of the villages that have schools providing primary level education, an average of 1.2 teachers provide the teaching for 40 pupils at all grade levels. As McDaniel (2000) points out, "teacher strikes are common, and classes are suspended for weeks at the time. Few books and basic supplies are available. Rural teachers often receive their pay late and ask local families to supplement their income".

4. EMPIRICAL FRAMEWORK

To examine the potential role of education on forest clearance through its labor market effects, three associations are analyzed using three separate regression models, i.e., the association between the household's head education with (1) forest clearance, (2) participation in wage employment and (3) wages. To examine the association between education and forest clearance, this study compares forest clearance among households that vary in their education levels but are otherwise similar in their observed characteristics. To ensure that a comparison is made among households that face similar village characteristics, the variation across villages is controlled for by using dummies for the three study sites, variables for various village characteristics and village dummies that absorb the remaining inter-village differences. To further ensure that the comparison is among households that are similar in their other observed household characteristics, control variables for the characteristics of households and their heads are added.

The general Ordinary Least Square (OLS) model[9] estimated is:

$$Y_{i,j,k} = E_{i,j,k}\,\beta + S_{i,j,k}\,\phi + H_{i,j,k}\,\alpha + V_{j,k}\,\gamma + R_{k} + \varepsilon_{i,j,k} \qquad \text{[Equation 1]}$$

where i indexes households in village j in study site k, Y is the annual household's forest cleared in the agricultural year surveyed, E is the household head's years of education, S is the dummy for the expenditure shock in the year prior to the agricultural year surveyed, H is a vector of household and household characteristics, V is the vector of village characteristics and village dummies, R is a vector of the dummies for the study sites and ε is the standard error term. The model does not include the variables for past employment or expected future returns to wage labor or own farm work because household heads can consider their decision of working in wage labor and forest clearance afresh every dry season, as neither types of work require long term investments.

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[9] The Tobit model, generally used in previous household deforestation studies (Godoy et al., 1998a), is not appropriate because its assumption that forest clearance is truncated at zero would imply that forest

Variables to be explained

The variables to be explained in the first regression model are the amount of old-growth forest clearance, secondary forest clearance and the sum of the two types of forest clearance.

The explanatory variables of interest

The two explanatory variables of interest are the education of the household head and the dummy for expenditure shocks to the household. The education of the male head is the relevant education variable in the nuclear households (75% of the sample households) as his allocation of time on his family farm limits the amount of forest his household clears. For households with more than one male adult, however, the education of other male adults may also influence the amount of household forest clearance. As the information on other male adults is unavailable in this pilot survey, the model is estimated twice, first with the full sample and next with only the sub-sample of households that have only one adult male.

Two alternative measures of shocks are used, each with its own strengths and weaknesses. The first variable is a dummy for the occurrence of at least one death of a household member under 8 years old. This variable captures the expenditure shock to the households as children do not contribute as significantly as adults to the household labor supply. However, a positive correlation between this variable and forest clearance may capture other confounding effects. Plausibly, household heads with more education are both more able to obtain wage labor (thus, they clear less forest) and less likely to suffer child deaths in their households (child deaths are often due to poor hygiene) (Huanca, pers. comm.).

The second measure is a dummy for the occurrence of at least one death of a household member above the age of 8. The confounding effect of education on mortality is less problematic among older individuals as their mortality is not influenced as significantly by hygiene. Moreover, their deaths are unlikely to be systematically correlated with household heads' choice of working in wage labor or on their own farm. People who work on their own farms are not exposed to greater work-related mortality than are those who work in wage labor for ranchers, loggers, and farmers (Vadez, pers. comm.).

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clearance can be negative. In this dataset, the Tobit model gives larger estimates of the effect of education on forest clearance than does the OLS model.

Nevertheless, these deaths represent both an expenditure shock as well as shock to the household labor supply, if the one who dies is the household member who contributes significantly to household labor. Nevertheless, these two types of shocks would have opposing effects on forest clearance. The reduction in labor supply is likely to be associated with reduced forest clearance, while the shock in expenditure is likely to be associated, if at all, with increased forest clearance. A finding of a positive association between these deaths with forest clearance would suggest that the latter association is dominant. These shocks may influence the households for more than one agricultural year. Unfortunately, the pilot survey did not inquire about deaths that occur more than one year before the agricultural year.

Village level control variables

Key village characteristics are factors that influence the returns to forest clearance and wage labor. To capture the supply of wage employment, a dummy variable is included for the presence of potential employers close to or in the village, such as non-indigenous ranchers, loggers and farmers as well as non-governmental organizations and the Church. To capture the supply of old-growth forests, the variables of the distance to the closest town [10]and the distance from the village center to the nearest old-growth forests are used. Villages that have a greater supply of old-growth forest are further from the town and have their village center closer to the old-growth forests.

Tenure insecurity is another key village characteristic that influences forest clearance. Many non-indigenous outsiders have entered the areas, extracting logs and drilling for oil and expanding ranch and farm operations, despite the status of these study sites as indigenous territories. This competition for land may induce households to clear more forests in order to lay claim to the land before others do. Many villages surveyed report conflict with these encroachers over land or trees: 12 of 21 villages in Lomerio, 9 of 19 villages in Rio Maniqui and 2 of 19 villages in Rio Secure.

[10]The distance to the nearest town, using the general mode of transport (walking or by canoe), is estimated by the interviewer in consultation with the village head for an average able-bodied male. The results for the estimation models are similar when the alternative variable of the linear distance from village to town (as measured with a Global Position System instrument) is used.

The dummy for the occurrence of land and resource conflicts between members of a village and outsiders is used as measure for tenure insecurity, even though it is an imperfect measure. Some villages that face severe competition for land from outsiders may not report conflicts, as villagers who have disproportionately less power than outsiders may preemptively withdraw from potential conflict situations. Another problem with this variable is that it may capture the confounding effects of the distance of a village from the nearest town, as villages that are closer to the town are the ones most likely to face resource competition with outsiders. To reduce this problem, a separate (imperfectly measured) distance to town variable is included in the regression model.

Household level control variables

Household characteristics include the age of the male household head, his age squared, his Spanish fluency, the numbers of male adults, female adults and children, and a measure of how rich the household is. The age and age-squared variable captures the stage of the household head's life cycle. Because middle-aged men are more skilled than younger men and more energetic than older men, the relationship between wages, wage labor participation or forest clearance and wages is an inverted U. Spanish fluency is associated with greater wages, greater participation in wage labor and reduced forest clearance because Spanish-speaking households heads are more likely to be hired for administrative jobs and by Spanish-speaking non-indigenous ranchers and loggers. Although these households are mainly nuclear with two adults (the male head and his wife), several households have additional adults who may contribute to the household labor supply and to its consumption needs, and thus the number of adults is added as a control variable. The number of children is also added as a control variable, because children influence the consumption needs of the household.

A measure of how rich households are in the period prior to the agricultural year surveyed is included to examine whether there are systematic differences between poorer and richer households in their forest clearance and employment choices. As all households tend to purchase radios when they have extra earnings (Huanca, pers. comm.), the number of radios is used to rank how rich households are. Alternative measures such as the ownership of agricultural tools and animals are not appropriate as they are correlated with households' choice of employment: for example, household heads that work on their own farms are likely to rear more animals and own more farm tools.

4.1 OTHER ESTIMATION ISSUES

One concern in these estimation models is the omission of variables, such as 'ability' that are correlated with both (1) education and (2) forest clearance, wages or participation in wage labor, leading to an overstatement of the strength of the positive association between these variables. In other words, the omitted variable u_i that is correlated with E_i leads to an upward bias in the estimation of β.

$$Y_{i,j,k} = E_{i,j,k}\,\beta + S_{i,j,k}\,\phi + H_{i,j,k}\,\alpha + V_{j,k}\gamma + R_k + u_{i,j,k} + \varepsilon_{i,j,k} \qquad \text{[Equation 2]}$$

One potential but imperfect instrumental variable[11] for the household heads' education is their fathers' education. However, the attempt to use this variable as an instrument was unsuccessful, because of the limited variation if the household heads' fathers' education (83% had no education). As methods to control for 'ability' (Card, 1995) could not be applied to this data, the study proceeds with this caveat.

Another estimation issue is that error terms within the same village would be correlated and thus the standard error would require correction.

$$Y_{i,j,k} = E_{i,j,k}\,\beta + S_{i,j,k}\,\phi + H_{i,j,k}\,\alpha + V_{j,k}\gamma + R_k + \mu_{j,k} + \varepsilon_{i,j,k} \qquad \text{[Equation 3]}$$

Observations within the same village are correlated as they share the error term $\mu_{j,k}$. However, the use of village dummies solves this problem by absorbing the village specific error term (Deaton, 1987). To see this, Equation 3 can be rewritten with $\underline{V}\,\eta = (V_{j,k}\gamma + \mu_{j,k})$, leaving $\varepsilon_{i,j,k}$ as the standard error term.

It would have been useful to examine the association of forest clearance with the potential returns from alternative employment opportunities directly by including the latter variable in the regression models. Unfortunately, the survey did not collect information on the potential wages for each of the household heads, regardless of whether or not they actually participated in wage labor. In addition, the Heckman technique to generate these potential wages from the realized wages among those who participated in wage labor could not be implemented because of the absence of a variable that both influences participation in wage labor and does not influence the wages earned.

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[11]This variable can control for the confounding effects that arise from the household head's individual specific ability. However, this variable will not control for the confounding effects that arise from factors such as taste for modernity, as fathers and sons may share these characteristics.

5 ANALYSIS AND RESULTS

5.1 Are education and expenditure shocks associated with greater forest clearance?

The first regression model estimates Equation 2 using the dependent variable of annual amount of forest cleared (either old-growth forests, secondary forests, or the sum of both types of forests, respectively) and the explanatory and control variables described above. The results from Table 4 are discussed below. Estimates are significant at or above the 90% level unless stated otherwise.

A year of education is associated with a reduction of 0.050 hectares or 4.3% of the mean annual household's forest clearance of 1.17 hectares. This reduction is split fairly evenly between old-growth and secondary forest clearance, i.e., 0.026 hectares of household old-growth forest clearance (4.6% of the household's annual mean) and 0.024 hectares of secondary forest clearance (3.9% of the household's annual mean). The mean 3-year increase in education of the youngest cohort of household heads would thus be associated with a significant reduction in forest clearance, i.e., 13% of the household's mean annual forest clearance.

Spanish fluency is associated with a reduction of 0.19 hectares of forest clearance (16.2% of the household's annual mean). In breakdowns of types of forests, Spanish fluency is associated with a reduction of 0.11 hectares of old-growth forest clearance (19.6% of the household's annual mean) and 0.077[12] hectares of secondary forest clearance (12.6% of the household's annual mean).

Using the death of a household member above the age of 8 as a measure of an expenditure shock to the household reveals that this shock is associated with an increase of 0.22 hectares of old-growth forest clearance (39% of the household's annual mean). Using the alternative measure of a death of a person below the age of 8 shows that the shock is associated with a similar increase in old-growth forest clearance. This second measure of shock is also associated with an increase of 0.40 hectares of both types of forest clearance.

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[12]Although the estimate the association between Spanish fluency and secondary forest clearance is not significant at the 90%level, it is compatible with the estimates for old-growth forests and the sum of the two types of forests.

5.2 Are education and expenditure shocks associated with increased participation in wage labor?

The second regression model estimates Equation 2 with the household head's annual sum of days worked in wage employment for the agricultural year surveyed as the dependent variable and other variables as in the forest clearance model above. Table 5 reveals that a year of education is associated with an increase of 10.8 days in the household head's annual sum of workdays in wage employment (or 21 % of the household head's annual mean of 50.4 days). Spanish fluency is associated with an increase of 14 days (or 28% of the annual mean). The expenditure shock (deaths of person above the age of 8) is associated with an increase of 23.7 days (or 47% of the annual mean), while the alternative measure (deaths of children under 8) is associated with only half this increase but is not significant at the 90% level.

The regressions on forest clearance and days worked in wage labor are re-estimated using the sub-sample of households that have only one male adult. The magnitude of the reduced forest clearance and increased days worked in wage labor associated with an additional year of education found in the sub-sample is similar to that found in the full sample.

5.3 Is education associated with higher wages?

Due to data limitations discussed above, this study examines the association between education and realized wages for households that participate in wage labor despite the overestimates that would result from this censoring of the sample. Village dummies and a dummy for the presence of potential employers are included in the regression so that comparison is made among households within the same village that have a similar supply of wage employment. The wage equation estimated using OLS is

$$\ln W_{i,j,k} = E_{i,j,k}\beta + V_{j,k}\gamma + R_k + u_{i,j,k} + \varepsilon_{i,j,k} \qquad \text{[Equation 4]}$$

where ln W is the natural log of the mean daily wage, E is the years of education, and V is the vector of village dummies and the dummy for the presence of potential employers, $u_{i,j}$ is the potential omitted variable and $\varepsilon_{i,j\,k}$ is the error term. Table 7 reveals that the estimated returns to education are 2.6%. This estimate is about 2.4 times lower than the 6.3% figure reported for Bolivian households in La Paz and the state capitals (Chiswick et al, 2000). The fairly low estimated return to education results from the scarcity of skilled employment that pay higher wages, such as employment with NGOs, the church and village administration. Table 7 also reveals that as suspected, wages increase with age, but at a decreasing rate, suggesting an inverted U relationship between wages and age.

5.4 What are the associations between village factors and forest clearance?

The interpretation of the village level variables should be done cautiously as there are about 50[13] village level observations and some of these village-level variables may capture other village-level confounding effects. According to the regression on forest clearance (see Table 4), forest clearance is greater in villages that are further from the towns. This result is unsurprising as forests are generally more abundant further from the towns. An hour increase in the distance traveled is associated with an increase of 0.020 hectares of both types of forest clearance (or 1.7% of the annual household mean) or 0.013 hectares of old-growth forest clearance (or 2.3% of the annual household mean). Greater returns from agriculture, represented by higher price of corn, is associated with greater old-growth forest clearance. A doubling of the price of corn is associated with 0.026 hectares of increased old-growth forest clearance (or 4.6% of the annual household mean).

The regression on the days worked by the household head in wage employment finds that heads work more days in villages where there are potential employers (Table 5). The presence of potential employers is associated with an increase of 52.3 days worked by the household head in wage labor, a magnitude similar to the annual mean days worked in wage labor for household heads.

In the regression for forest clearance, the coefficient on conflict variable is not significant at the 90% level, but it has a negative sign. The conflict dummy, as suspected, is likely to have captured the effect of the villages being close to the town. Forest clearance is lower in these villages as a result of the lower supply of forests.

6 BENEFITS AND COSTS OF EDUCATION

The positive associations between education and forest clearance suggest a potential role for education in conservation, but the question arises about whether education is potentially a cost-effective tool. Estimates suggest that education is indeed a potentially cost-effective tool,

[13]Because of the lack of variation among households in 9 villages, the OLS estimation dropped these observations.

despite the time lag for education to take effect, even when conservative measures of benefits are used.

The global benefits from reduced forest clearance are substantial. The monetary value for carbon sequestered by averting forest clearance (calculated based on the costs of investing in alternative carbon abatement projects in developing countries) is about US$10 per tonne of carbon sequestered annually (Austin and Faeth, 2000). One hectare of forest clearance averted prevents the emission of 165 tonnes of carbon per year (US Department of Energy, 1999). Other values for forests, though important, are not readily available, including the value for biodiversity protection in Bolivia[14] and the existence value of these forests. Assuming a 5% discount rate, the net present benefit of carbon sequestration per hectare,[15] even if this benefit is realized only 14 years after the initial investment, amounts to US$7095.

The construction and operating costs for a primary school with 5 grades include the building materials of $1000 for a two-room school for 40 pupils, a teacher's annual salary of $1440, and annual supplies of $10 per pupil. The labor costs to construct the school are excluded from the costs to be borne by the global community as local communities (who receive some private benefits from education) generally provide the labor required for school-building in these areas (McDaniel, pers. comm.). The school construction and the operating costs for 5 years sum to $8,965, assuming a 5% discount rate.[16]

Table 8 reveals that under reasonable assumptions, the potential conservation-related benefits from schooling the global society receives exceed the costs of schooling it would incur. The village school project, assuming a 5% discount rate, yields a net benefit even under conservative assumptions. It is assumed that only 8 students out of 40 that attend school for 5 years complete 3 years of schooling and as adults, they each refrain from clearing 0.15 hectares of forests annually for 11 years. If a larger percentage of students complete more years of education, the net benefits would be greater, or alternatively, fewer years of averted deforestation would be required for the village school project to yield net benefits.

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[14]The monetary value of biodiversity protection could potentially be calculated based on the Global Environment Fund's grants to Bolivia for biodiversity protection.
[15]The figures on the gross carbon emission from deforestation is used because even if forests are left to regenerate, a significant time lag would be required before the new vegetation sequesters carbon on net (M.Cochrane, tropical ecologist, pers. comm.).
[16]Monetary estimates of children's contribution to household labor, an opportunity cost of schooling, are unavailable.

7 CONCLUSION

While this study cannot make causal inferences, it finds that expenditure shocks are associated with an increase of 39% in the household's mean annual old-growth forest clearance. Even if households clear additional forests only while they generate additional income to cope with the shock, and then allow the forests to regenerate, this one-time clearance of old-growth forest would permanently reduce its biodiversity value. This finding highlights the important role of forests as a 'social safety net' for populations who live in forested areas, even when alternatives such as wage employment are available. This finding also suggests the potential role for devices to cope with expenditure shocks, such as credit, to reduce forest clearance. Nevertheless, excessive credit can be counterproductive from a conservation point of view, if large amounts of credit had previously constrained agricultural expansion and thus forest clearance.

This study also finds that education is associated with reduced forest clearance (a reduction of 4.3% of the annual mean household forest clearance), increased wages (the estimated returns to education is 2.6%), and increased participation in wage employment (an increase of 21% of the annual mean household head's wage labor work days). Taken altogether, these associations suggest that education can potentially reduce forest clearance by increasing the returns of alternative employment opportunities, though further research is required to establish causality.

Despite the generally low educational opportunities in the area, increased education among the youngest cohorts could potentially have a significant impact on reducing forest clearance. Based on the OLS estimate that a year of schooling is associated with an annual reduction of 0.05 hectares of forests, the 3-year average increase in education among the youngest cohorts can potentially be associated with 0.15 hectares of reduced annual forest clearance (13% of the household's mean annual forest clearance). Nevertheless, there is a limit to how many household heads will switch out of own farming from each of these communities, as some level of farming would be required in each community to fulfil the local demand for rice and corn.[17]

The negative association between education and forest clearance suggests that education can potentially generate positive externalities such as conservation-related carbon sequestration,

[17]Purchasing food from the town is expensive.

biodiversity protection, and the existence value of intact forests. This global externality is significant, even if conservative estimates are used: averting one hectare of deforestation for ten years yield benefits of carbon sequestration worth US$7095.[18] Education is potentially a cost-effective tool for conservation: a rough cost-benefit analysis suggests that under reasonable assumptions, the provision of a village school yields net benefits, despite the time lag for educational investments to yield conservation benefits. The provision of these educational subsidies by the global community to pay for the benefits they receive from conservation would expand the scarce educational opportunities in these territories.[19]

The goal of conservation can only be achieved if household heads that switch out of own-agriculture into wage labor enter environmentally benign employment. However, such employment opportunities are scarce in the study sites. A catch-22 situation exists. As long as returns to education are low due a lack of supply in skilled employment, there is little incentive for households to invest in education. Projects that generate environmentally benign employment are unlikely to enter these areas unless there is a core group of educated persons to provide the initial support for these projects (McDaniel, 2000). For example, the sustainable forestry project in Lomerio faced labor shortages of moderately educated personnel (including field workers who keep inventories on the ecological sustainability of the logging project) and highly educated personnel for managing the project (McDaniel, 2000).

Education could potentially reduce forest clearance by other channels such as agricultural intensification, out-migration, fertility reduction and political organization. The first three are not likely to operate in the study site, but may operate elsewhere. Households do not have access to intensive agroforestry technologies, have a low 7% rate of out-migration (Censo Indigena, 1994-5), and already practice traditional methods of birth-spacing, herb-based oral contraceptives and sexual continence (Huanca, 2000).

The effect of education through the fourth channel of political organization could not be studied using this survey data, but it can potentially play a powerful role. At present, encroachment from outsiders (Jones, 1995; Turner, 1993) and the collusion of indigenous leaders

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[18]Carbon sequestration is assumed to occur 14 years after the initial investment into schooling.
[19]It is likely that the lack of schooling in these areas is driven by the lack of supply of schooling opportunities and not by the lack of demand for schooling. Many rural people regard schooling as a way to climb the social ladder. Children's contribution to agricultural production does not prevent their school

with logging firms lead to high deforestation rates (Jones, 1995; Turner, 1993). Universal education would empower these communities among the wider Bolivian public to advocate for the exclusion of outsiders from their territories (Brysk, 2000) and indeed, it has served as an empowerment tool among the Aymara in Bolivia and the Shuar and Octavolas in Ecuador (Brysk, pers. comm.).

Within the study sites, the few educated members in some villages have cooperated with logging firms to extract timber from the village forests, often without the consent of the rest of their community (Huanca, pers. comm.). Although universal education would not necessarily stop these logging contracts, it could potentially increase the ability of the local community to keep the leaders accountable. Logging, if it proceeds, would be at a rate optimal for the community, and not artificially hastened by the need of a particular leader to mine the resource while he is still in power.

The importance of reducing deforestation, both for conservation purposes and for the survival of indigenous peoples, and the finding that education is associated with reduced forest clearance, call for further research. Follow-up surveys across a wider variety of villages in the Bolivian lowland have been planned. In particular, it is hoped that the new surveys will find sufficient enough variation in the household heads' fathers' education for this variable to serve as a potential (though imperfect) instrument for the education of household heads.[20] Thus, the causal relationship, if any, between education and forest clearance can be examined.

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attendance as villages that have schools have adjusted the school calendar to allow children to work when they are most needed (McDaniel, pers. comm).

[20]see footnote 11.

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Table 1: No of households (HHs) sampled in surveyed villages

Study sites	No. of surveyed villages in the study sites	No. of HHs surveyed	Total no. of HHs in the surveyed villages	% of HHs in surveyed villages that were sampled
Rio Secure	21	223	511	43.6%
Lomerio	20	218	626	34.8%
Rio Maniqui	18	208	341	60.9%
All	59	649	1478	43.9%

Table 2: Percentage of the indigenous households in lowland Bolivia that were surveyed

Ethnic groups ▶	Chiquitano	Mojeno	Tsimane	Yuracare	Total
Surveyed:					
Households	220	132	238	62	652
Villages	20	13	20	7	60
Population:					
Households	7876	3068	1022	525	12491
Population	48524	19759	5124	3339	76746
% of households that was surveyed:	2.8%	4.3%	23%	11.8%	5.2%

Source: Population figures from Censo Indigena 1994-5 (1996)

Table 3: Descriptive statistics of the survey data

Variables	Mean	Std. Dev.
Annual household forest clearance in hectares	1.17	0.93
(i.e. the sum of old growth & secondary forest clearance)		
Annual household clearance of old-growth forests in hectares	0.56	0.63
Annual household clearance of secondary forests in hectares	0.61	0.63
Annual days worked in wage labor	50.4	83.0
Realized daily wage for those who participate in wage labor†	24.2	20.1
Log of the realized daily wage for those who participate in wage labor†	3.01	0.58
Years of education of the household head	2.9	3.0
Dummy for Spanish fluency of the household head	0.94	0.41
Age of the household head in years	39	13.4
No. of adult males	1.3	0.68
No. of adult females	1.3	0.65
No. of children	3.4	2.2
Dummy for expenditure shocks in the preceding agricultural year:		
Death of a household member above the age of 8	0.055	0.23
Death of a household member below the age of 8	0.10	0.33
A measure of how rich the household is in the preceding agricultural year:		
The no. of radios owned by the household	0.78	0.83
Measures of the supply of primary forest in a village:		
Distance from the village center to the nearest old-growth forests in minutes	37	45
Distance from the village to the nearest town in hours	18	14.3
Dummy for at least one conflict between villagers and outsiders	0.56	0.50
Measures of the gross returns to agriculture in a village:		
Price of rice in the village in bolivianos/arrobas	12.7	9.0
Price of corn in the village in bolivianos/arrobas	13.2	4.4
Measure for the supply of wage employment in a village:		
Dummy for the presence of potential employers in or near the village	0.31	0.47
No obs. = 649 households		

Notes: All variables are for the agricultural year surveyed, except the expenditure shocks and the measure of how rich the household is are for the year preceding the agricultural year surveyed. 1 USD=5.23 Bolivianos
1 arroba = 10 kg

Table 4: The association of education and expenditure shocks with the annual household forest clearance using OLS

Dependent variable: Annual household forest clearance ►	The death of at least one HH member is used as a shock					
	HH member above 8 years old			HH member below 8 years old		
	Sum of both types of forests	Old growth forests	Secondary forests	Sum of both types of forests	Old growth forests	Secondary forests
	(1)	(2)	(3)	(4)	(5)	(6)
▼ Explanatory variables:						
Years of education of the HH head	-.050**	-.026**	-.024**	-.046**	-.024**	-.023*
	(.016)	(.011)	(.011)	(.016)	(.011)	(.11)
Dummy for Spanish fluency	-.19**	-.11*	-.077	-.16*	-.094†	-.063
of the HH head	(.095)	(.065)	(.066)	(.094)	(.065)	(.067)
Age of the household head	-.0061	.0034	-.010	-.0042	.0056	-.010
	(.018)	(.012)	(.013)	(.018)	(.012)	(.013)
Age of the household head squared	.00012	-.00002	.00014	.00012	-.000027	.00015
	(.00020)	(.00014)	(.00014)	(.00020)	(.00014)	(.00014)
No. of adult males	.048	.014	.035	.045	.010	.035
	(.060)	(.042)	(.042)	(.060)	(.041)	(.042)
No. of adult females	.015	.013	.0021	.015	.013	.0032
	(.059)	(.041)	(.042)	(.059)	(.041)	(.042)
No. of children	.021	.030**	-.0087	.017	.026**	-.0097
	(.019)	(.013)	(.013)	(.019)	(.013)	(.013)
Dummy for the death of at least	.17	.22**	-.046	.40**	.31**	.095
one HH member	(.16)	(.11)	(.11)	(.12)	(.085)	(.087)
The no. of radios owned by the HH	.094**	.025	.070**	.094**	.028	.067**
	(.046)	(.032)	(.032)	(.045)	(.031)	(.032)
Distance from the village center to the	.0018	.0013	.00045	.0017	.0013	.00042
nearest old growth forests in minutes	(.0031)	(.0021)	(.0022)	(.0031)	(.0021)	(.0022)
Distance from the village to the	.020**	.013**	.0074	.021**	.014**	.0072†
nearest town in hours	(.0071)	(.0049)	(.0050)	(.0070)	(.0049)	(.0050)
Dummy for at least one conflict	-.31	-.086	-.22	-.30	-.081	-.22
between villagers and outsiders	(.27)	(.19)	(.19)	(.27)	(.18)	(.19)
Price of rice in the village	.013**	.0057†	.0076*	.013**	.0057†	.0075*
(in bolivianos/arrobas)	(.0056)	(.0039)	(.0039)	(.0055)	(.0038)	(.0039)
Price of corn in the village	-.0070	.0087	-.016	-.0073	.0082	-.016
(in bolivianos/arrobas)	(.021)	(.015)	(.015)	(.021)	(.014)	(.015)
Dummy for the presence of potential	-.30	-.13	-.17	-.30	-.13	-.18
employers in or near the village	(.32)	(.22)	(.22)	(.31)	(.22)	(.22)
Dummy for the Rio Secure site	-.49	-.51*	.022	-.50	-.52*	.014
	(.44)	(.30)	(.31)	(.43)	(.30)	(.31)
Dummy for the Lomerio site	1.0**	.26	.74**	.97**	.25	.72**
	(.40)	(.28)	(.28)	(.40)	(.28)	(.28)
Village dummies are included						
No obs.	622	622	623	621	621	622
Adjusted R-squared	.15	.12	.094	.16	.13	.094

Notes: Because of the lack of variation among households in 9 villages, the OLS estimation dropped these observations. The final sample analyzed includes only 50 villages. The dummy for the Rio Maniqui site is omitted.
** indicates significance at the .05% level. *indicates significance at the .10% level. † indicates significance at the .15% level.

Table 5: The association of education and expenditure shocks with the annual days the HH head worked in wage labor using OLS

	The death of at least one HH member is used as a shock	
	above 8 years old	below 8 years old
Dependent variable: Annual days the HH head worked in wage labor		
▼ Explanatory variables:		
Years of education of the HH head	10.8**	10.8**
	(1.3)	(1.3)
Dummy for Spanish fluency of the HH head	14.0*	14.5*
	(7.7)	(7.7)
Age of the household head	.74	1.0
	(1.5)	(1.5)
Age of the household head squared	-.011	-.013
	(.016)	(.016)
No. of adult males	-.21	-.54
	(4.9)	(4.9)
No. of adult females	5.7	5.5
	(4.8)	(4.8)
No. of children	.87	.69
	(1.5)	(1.5)
Dummy for the death of at least one HH member	23.7*	12.1
	(13.2)	(10.1)
The no. of radios owned by the HH	5.3	5.7†
	(3.7)	(3.7)
Distance from the village center to the nearest old growth forests in minutes	.17	.17
	(.25)	(.25)
Distance from the village to the nearest town in hours	-.26	-.19
	(.58)	(.58)
Dummy for at least one conflict between villagers and outsiders	14.7	14.9
	(21.8)	(21.9)
Price of rice in the village (in bolivianos/arrobas)	-.030	-.017
	(.45)	(.45)
Price of corn in the village (in bolivianos/arrobas)	1.4	1.3
	(1.7)	(1.7)
Dummy for the presence of potential employers in or near the village	52.3**	52.7**
	(25.5)	(25.6)
Dummy for the Rio Secure site	-3.3	-3.8
	(35.5)	(35.5)
Dummy for the Lomerio site	-13.3	-12.6
Village dummies are included	(32.8)	(32.9)
No. obs.	623	622
Adj-R-squared	.22	.22

** indicates significance at the .05% level. *indicates significance at the .10% level.
† indicates significance at the .15% level.

Table 6: The association of education with forest clearance and days worked in wage employment using the sub-sample of households with only one male adult, estimated with OLS

Dependent variable ▶	Annual HH clearance of both types of forests (1)	Annual HH clearance of old growth forests (2)	Annual HH clearance of of secondary forests (3)	Annual days worked in wage labor by HH head (4)
▼ Explanatory variables:				
Years of education of the HH head	-0.066**	-.0040**	-0.026*	11.6**
	(.020)	(.014)	(.014)	(1.6)
Dummy for Spanish fluency	-0.21**	-.093	-.12*	14.5*
of the HH head	(.10)	(.071)	(.073)	(8.1)
Age of the household head	0.012	.023†	-.012	1.4
	(.023)	(.016)	(.016)	(1.7)
Age of the household head squared	-.00010	-.00027†	.00018	-.018
	(.00026)	(.00017)	(.00018)	(.02)
No. of adult females	.024	.045	-.020	1.7
	(.082)	(.056)	(.057)	(6.4)
No. of children	.0000067	.020	-.020	-2.5
	(.025)	(.017)	(.15)	(1.9)
Dummy for the death of at least	-.13	.084	.060	35**
one HH member	(.21)	(.14)	(.038)	(16.4)
The no. of radios owned by the HH	.072	.014	-.0016†	2.8
	(.055)	(.037)	(.0024)	(4.3)
Distance from the village center to the	-.00032	.0012	.0067	.16
nearest old growth forests in minutes	(.0035)	(.0023)	(.0060)	(.27)
Distance from the village to the	.019**	.013**	-.0053	-.27
nearest town in hours	(.0087)	(.0058)	(.26)	(.67)
Dummy for at least one conflict	-.049	-.045	.012	7.3
between villagers and outsiders	(.37)	(.25)	(.0055)	(28.5)
Price of rice in the village	.014	.0020	-.042**	.20
	(.0079)	(.0053)	(.030)	(.61)
Price of corn in the village	-.017	.0020	.073	-.20
	(.044)	(.0053)	(.39)	(3.4)
Dummy for the presence of potential	-.30	-.37	.49	70.1†
employers in or near the village	(.57)	(.38)	(.52)	(43.9)
Dummy for the Rio Secure site	-.38	-.87*	.49	24.9
	(.74)	(.50)	(.52)	(57.6)
Dummy for the Lomerio site	1.1	.097	.97**	2.5
	(.67)	(.45)	(.47)	(52.3)
Village dummies are included				
No obs.	463	463	464	464
Adjusted R-squared	.12	.10	.07	.22

Notes: HHs with more than one adult were dropped from this sub-sample. The regression results on education using this sub-sample is similar with the results when the full sample is used.
** indicates significance at the .05% level. *indicates significance at the .10% level.
† indicates significance at the .15% level.

Table 7: The association between education and wages in the wage labor sector

Dependent variable: days HH head worked in wage labor	
▼ Explanatory variables:	
Years of education of the HH head	.026**
	(.011)
Dummy for Spanish fluency of the HH head	-.0014
	(.059)
Age of the household head	.048**
	(.014)
Age of the household head squared	-.00051**
	(.00016)
Dummy for the presence of potential employers in or near the village	-.082
	(.36)
Distance from the village to the nearest town in hours	.0072
	(.0066)
Dummy for the Rio Secure site	.41
	(.39)
Dummy for the Lomerio site	.61
	(.46)
Village dummies are included	
No. obs.	372
Adj-R-squared	.29

Notes: The sample includes only those who participated in wage employment. The estimate of the returns to education would be biased in the positive direction due to this censoring of the sample. Heckman sample selection correction could not be implemented.
** indicates significance at the .05% level. *indicates significance at the .10% level.
† indicates significance at the .15% level.

Table 8: The conservation-related net present benefits from constructing a village school

▼ Assumptions: Discount rate	▼ Assumptions: % of students among the 40 pupils who complete at least 3 years of education	Gross Present Benefits from from 11 years of carbon sequestration	Gross Present Cost of a village school	Net Present Benefits, from the village school project	Years of carbon sequestration required for the village school project to yield a positive Net Present Value
5%	20%	$9,151	$8,965	$186	11
	40%	$18,306	$8,965	$9,341	5
2%	20%	$15,219	$9,761	$5,458	7
	40%	$30,440	$9,761	$20,679	3.3

Notes: It is assumed that students who complete at least 3 years of education reduce their forest clearance by 0.15 hectares every year for 11 years, and by averting deforestation, they contribute to carbon sequestration. The deforestation is averted, or equivalently carbon sequestration starts, 14 years after the school is constructed.

Essay 3

Does Mexico Specialize in Polluting and Injurious Industries?

Empirical Evidence from NAFTA-related US-Mexican Trade Expansion

Abstract

Trade expansion along with weaker environmental protection in developing countries has raised concerns that developing countries have specialized in the more polluting and injurious industries. I examine the pollution intensity of the NAFTA-related expansion in US-Mexican bilateral trade in the manufacturing sector using new detailed measures of air, water, metal and toxic pollution intensities and injury rates at the 4-digit Standard Industrial Classification level. Based on this resolution of pollution and injury measures, I do not find strong evidence of greater growth in the shares of US net imports from Mexico in the more polluting or injurious industries between the pre and post-NAFTA periods.

1. INTRODUCTION

The expansion of trade between developed and developing countries, along with weaker environmental and worker protection in the latter, has raised concerns that trade may encourage developing countries to specialize in manufacturing industries that create more pollution and worker injury. Understanding whether such specialization has occurred is important for public policy. First, in those developing countries where weaker environmental and worker protection do not result from its well-informed public choosing to place little weight on environmental and worker protection, such specialization can result in economic inefficiency (World Bank, 1992). Mechanisms to ensure that environmental and worker protection policies are at the level of public preference would be crucial. Second, public protests in Seattle and elsewhere against trade expansion and the proposed Free Trade Agreement of the Americas (FTAA) have been fueled in part by a belief in the existence of such a specialization (Nordstrom and Vaughan, 1999). Yet empirical evidence on whether such a specialization has occurred is scarce.

Trade theory predicts that as countries move from autarky to freer trade in response to trade liberalization measures, they would move a greater share of their production from producing goods for domestic consumption towards producing goods in which they have a comparative advantage. If Mexico in its bilateral trade with the US has a comparative advantage in producing goods that create more pollution and worker injury in the production process, as this bilateral trade expands over time, the shares of US net imports from Mexico would show greater growth in the more polluting and injurious industries. The North American Free Trade Agreement (NAFTA) that came into force in January 1994 expanded US-Mexican trade. This study asks whether during the transition from the pre-NAFTA years to post-NAFTA years, the shares of US net imports from Mexico in the manufacturing sector have shown greater growth in the more polluting or injurious industries.

Whether Mexico has a comparative advantage in the more polluting or injurious industries is an empirical question. Because it is cheaper to cause pollution and compensate workers for dangerous work in Mexico than it would be in the US, there is an incentive for the more polluting and injurious production to take place in Mexico (Walter, 1982; Copeland and Taylor, 1994; Copeland and Taylor, 1997). However, the savings from lower pollution costs and worker injury compensation costs in Mexico may not be sufficient to offset other production considerations such as the need for skilled workers, the immobility of sunk physical capital and the high costs of transporting perishable or hazardous goods from Mexico to the US.

At present, there is little empirical evidence on whether Mexico has specialized in the more polluting or injurious industries. The one post-NAFTA study (Hufbauer et al, 2000) that evaluates the impact of NAFTA on the environment does not examine the empirical data on trade patterns. Empirical studies in the pre-NAFTA years find mixed evidence on whether Mexico has specialized in polluting industries. Grossman and Krueger (1993) and Kahn (2001) report no evidence of Mexico's specialization in such industries. However, as polluting industries tend to be more capital intensive, these studies that examine patterns of trade in a cross section of industries may fail to isolate the effect of pollution intensity from the confounding effect of physical capital intensity. The use of coarse measures for pollution intensity, i.e. pollution abatement costs at the 3-digit SIC level (Grossman and Krueger, 1993) and a single measure of the weight of Toxic Release Inventory pollutants (Kahn, 2001), weakens the ability to detect such a specialization. The statistically insignificant estimates on pollution intensity may be driven by the small sample size of about 140 3-digit SIC industries for 1987 alone (Grossman and Krueger, 1993). In contrast, Levinson and Taylor (2001) who examine the changes in the shares of pollution abatement costs within 3-digit industries across time report preliminary evidence that industries which face greater increases in these costs show larger increases in the shares of US net imports from Mexico. However, their results would be hard to interpret if the changes over time in the shares of pollution abatement costs at the 3-digit SIC-level are driven by composition changes in the 4-digit SIC industries.

2. TRADE AND SPECIALIZATION

NAFTA-related expansion in bilateral US-Mexican trade can provide some insights on the potential environmental impact of trade between the US and the rest of Latin America under the proposed FTAA as well as the environmental impact of trade between developed and developing countries more generally. The US and Mexico have the characteristics of the stereotypical developed and developing countries engaged in trade. The US has stronger enforcement of environmental and worker protection laws than does Mexico, both before and after NAFTA. Since the 1970s, the US has enforced its environmental regulations, including the Clean Air Act, Clean Water Act and the Comprehensive Environmental Response, Compensation and Liability Act (for hazardous wastes) (Gray, 1987), as well as its worker protection laws (Gray and Jones, 1991). Although Mexico enacted its comprehensive set of environmental laws, the General Law of Ecological Equilibrium and Protection of the Environment (LGEEPA) in 1988, its enforcement of environmental laws has lagged behind that of the US.

The growth of US-Mexican bilateral trade during the transition from pre-NAFTA to post-NAFTA years provides an opportunity to examine empirically the popular view that developing countries have specialized in polluting and injurious production in their trade with developed countries. Production within Mexico, including production for exports to US markets, is expected to increase post-NAFTA because NAFTA improves the security of investments within Mexico and the security of entry into the US for goods produced in Mexico (Weintraub, 1997). Under NAFTA, the Mexican government agreed to protect foreign investment in Mexico, including to treat foreign investment fairly in accordance with international law, to not impose performance requirements, and to not nationalize or expropriate these investments except under narrow well-defined circumstances (Hufbauer et al, 2000). The US government agreed to remove tariffs and quantitative restrictions on US imports from Mexico (Weintraub, 1997). Trade theory predicts that in response to trade liberalization, countries would shift a greater fraction of their production from previously fulfilling domestic needs towards producing goods in which they have a comparative advantage. If indeed Mexico has a comparative advantage in the more polluting and injurious industries in its trade with the US, as this trade expands in response to NAFTA, Mexico would shift a greater fraction of its production towards producing these goods (Copeland and Taylor, 1994; Copeland and Taylor, 1997). Thus between the pre-NAFTA and the post-NAFTA years, the shares of US net imports from Mexico would show greater growth in the more polluting or injurious industries than in the less polluting or injurious industries.

3. EMPIRICAL FRAMEWORK

To determine whether Mexico has a comparative advantage in polluting industries, it is necessary to isolate other factors that may confound the effect of pollution intensity on the shares of US net imports from Mexico. In particular, because industries that are more polluting tend to be more intensive in physical capital and thus potentially less likely to locate or relocate to Mexico, it is important to control for the influence of physical capital intensity on these net import shares. The identification strategy used in this paper is to apply industry fixed effects to control for the cross-industry variation in the initial pre-NAFTA levels of net import shares and to then examine the growth in the net import shares of the more polluting or injurious industries relative to their less polluting or injurious counterparts during the transition between the pre-NAFTA and the post-NAFTA years.

The study also applies a second specification to address one other estimation issue. More polluting industries tend to be more intensive in physical capital. Industries that are more intensive in physical capital may grow more slowly than industries that are less intensive in physical capital. As polluting industries tend to be more intensive in physical capital, it is important to control for the variation in growth rates of industries that result from their differences in physical capital intensity, or analogously, from their differences in human capital intensity. The estimation model accounts for differences in the growth rates of net import intensity resulting from the inter-industry variation in the physical (or human) capital intensity. In ranking the pollution and injury intensity across industries, I assume that globally some industries are more polluting than other industries as a result of a global technological constraint I use pollution intensity and injury rates measured in the US to rank the global pollution or injury intensity of industries. To examine the extent to which this assumption holds, it would be useful to compare the pollution and injury intensities measured in the US with those measured in Mexico, should the latter become available in the future.

Although this paper uses NAFTA-related trade expansion to examine if Mexico has a comparative advantage in the more polluting or injurious industries, policy changes that coincided with NAFTA could have reduced Mexico's comparative advantage in such industries, if indeed it had such an advantage previously. The Mexican Federal Attorney-General for the Environment (PROFEPA) raised its annual number of complete inspections of establishments between the pre-NAFTA and the post-NAFTA years.[1] The Mexican government also implemented an environmental auditing program for public-sector industries and large private industrial groups.[2] The number of firms undertaking audits and committing to action plans to achieve compliance has increased from 246 and 99 in 1992-4 to 571 and 388 in 1995-7,

[1] PROFEPA increased its inspections of establishments (including non-manufacturing establishments) from 4,600 in 1992 to 11,800 in 1997.

[2] The audit program that began in November 1992 would become effective after a time lag and its effective phase is likely to have coincided with NAFTA.

respectively (PROFEPA, 2000). Under the North American Agreement on Environmental Cooperation (NAAEC), citizens of NAFTA countries can submit complaints to the NAFTA-created Council for Environmental Cooperation (CEC) against NAFTA governments that fail to enforce their domestic environmental laws. A NAFTA government can also submit complaint against another NAFTA government that has shown 'persistent failure to enforce its environmental laws' (Hufbauer et al, 2000).

However, these policy changes may not remove Mexico's comparative advantage in polluting industries if one existed prior to NAFTA. Only a fraction of firms have faced inspection and have undertaken environmental action plans.[3] The NAFTA mechanisms may not increase the enforcement of Mexican environmental laws.[4] The citizens complaint process faces significant institutional obstacles: the Mexican public faces large expenses in bringing a complaint to the CEC that is headquartered in Montreal, the CEC will gather facts on the complaint only if two-thirds of its members approve, and even if the complaint is substantiated, the CEC is not required to make any recommendations to rectify the situation and indeed, it has not done so (Hufbauer, 2000). The US and Canada has not invoked the government to government complaint mechanism. Even if Mexico specializes in the more polluting or injurious industries, it is not likely that the US or Canada will invoke this complaint mechanism as they benefit from Mexico's willingness to bear environmental costs.

This paper's identification strategy that relies upon changes between the pre-NAFTA and the post-NAFTA years would be problematic if other significant events or policy changes that coincided with NAFTA influence the growth of net import intensity in the more polluting industries relative to that in the less polluting industries. Fortunately, one important event that occurred not long after NAFTA came into force, i.e. the Mexican government's devaluation of the peso in December 1994, is likely to have similar effects on the imports in both the more and

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[3] The PROFEPA reports that it has inspected about 12,800 establishments (including non-manufacturing establishments) annually since 1993. The PROFEPA's jurisdiction covers about 25,000 manufacturing establishments and a large number of other non-manufacturing establishments. Local environmental agencies oversee other manufacturing establishments, but figures are not available on their inspection rate. Although the PROFEPA detected a decreasing number of gross violations between 1992-7, this data does not necessarily indicate firms' increased compliance (PROFEPA, 2000). The decrease may reflect the compositional changes in the types of firms inspected, given that the PROFEPA has expanded its inspections from the most polluting facilities to a broader set of industries (PROFEPA, 2000).

[4] The direct citizen complaint mechanism in which the Mexicans complain directly to the PROFEPA is a better mechanism than the NAFTA-created indirect citizen complaint mechanism. The larger number of

less polluting industries. Although the devaluation reduced the price of US net imports, it would not have affected the prices of the imports of the more polluting relative to those from the less polluting industries. This reasoning also applies to the net imports of the more injurious industries relative to the less injurious industries.

This paper asks the simple descriptive question of whether in the transition from the pre-NAFTA to the post-NAFTA years, the shares of US net imports from Mexico showed greater growth in the more polluting industries relative to that in the less polluting industries. I do not ask the more complicated question of whether NAFTA per se intensified Mexico's specialization in polluting industries, if such a specialization indeed existed. To address the latter question, the study would need to examine if NAFTA changed the existing trend of growth rates of the shares of US net imports from Mexico in the more polluting industries relative to those in the less polluting industries.

4. DATA DESCRIPTION

Data on US imports from Mexico and US exports to Mexico are from the NBER trade CDs for the years 1987-1994 (Feenstra, 1996 and 1997).[5] Data on US imports from Mexico for 1995-9 are from the US Census Import History CD (US Census, 1999a) while data for US exports to Mexico 1995-9 are from the US Census Export History CD (US Census, 1999b). Data on injury rates for US industries are from the Bureau of Labor Statistics (Bureau of Labor Statistics, 2001). Pollution abatement operating costs (PAOC) are from the Pollution Abatement Capital and Expenditure Survey (US Census, 1989-1994). Wages for workers with less than high school education are from the State of Working America (Mishel et al, 1998).

Data on employment, payroll, energy expenditure, domestic shipments, and value-added for US industries are from the NBER's productivity database for 1987-1996 (Battelsman and Gray, 1996). For 1998-9, the data for these variables are from the Census of Manufacturers in 1997 and the Annual Survey of Manufacturers. Because data for 1998-9 are in the 1997 North American Industrial Classification System (NAICS), I have concorded these data to the 1987 SIC

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intermediaries involved in the latter raises transaction costs.

[5]The US Census is the original source for both the 1987-1995 and the 1995-9 import series. The same is true for the 1987-1995 and the 1995-9 export series.

classification using a similar method applied by Battelsman and Gray (1996). I build a concordance using the 1997 Census that tabulates data in both the NAICS and the SIC. The concordance is straightforward if a NAICS industry maps uniquely to a SIC industry. When there is no 1:1 correspondence between a NAICS industry and a SIC industry, I use the following method. For example, SIC-2048 comprises of NAICS-311611 and NAICS-311119. in 1997, 0.086% of NAICS-311611 employment is from SIC-2048 while all of NAICS-311119 employment is from SIC-2048. To convert the 1998 NAICS data into SIC data, for example, to obtain employment data for SIC-2048 in 1998 from the 1998 NAICS data, I take 0.086% of 311611's employment in 1998 and all of 311119's employment in 1998. This method assumes that the relationship between the composition of industries in the SIC and NAICS classifications in 1998-9 are similar to that in 1997. This assumption is reasonable as the window of time between 1997-9 is fairly short.

Physical measures of pollution intensity of US manufacturing industries in 1987 are from the World Bank Industrial Pollution Projection System (IPPS) project (Hettige et al, 1994). The pollutants measured in the IPPS project are relevant to the discussion of Mexico's potential comparative advantage in the polluting industries in its bilateral trade with the US because the industrial emissions of these pollutants are strictly regulated in the US. Air, water, toxic and metal pollution intensities are expressed as a ratio of the weight of the pollutants produced within a 4-digit SIC industry to the value-added within that industry. The IPPS project examined the population of 200,000 US manufacturing firms, combining economic information from the 1987 US Census of Manufacturers with the US Environmental Protection Agency's (EPA) information on air, water and solid waste emissions in 1987. For air pollution, the EPA's 6 criteria air pollutants are measured i.e. particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) volatile organic compound (VOC) and PM-10 (particulate matter below 10 micron). For water pollution, two measures are used i.e. the total suspended solids (TSS) and the biological oxygen demand (BOD). Toxic materials include all chemicals (including bioaccumulative metals) listed as toxic under the 1987 Toxic Release Inventory. The amount of toxic materials (including bioaccumulative metals) and the amount of metals are recorded separated based on the media into which they are released (i.e. water, air or as solids). Several measures overlap (e.g. an emitted chemical can both raise the BOD measure and the measure of toxic metal released to water and a metal would raise both the metal and toxic pollutant measures) while others do not (e.g., the criteria air pollutants are distinct from the toxic pollutants released to air).

These measures sum the weight of different pollutants, instead of weighting them by their danger posed to human and ecosystem health. Unfortunately, the ranking of pollution intensity based on the latter is unavailable at present. Nevertheless, these measures of pollution have a broad relationship with the dangers posed by these pollutants to human and ecosystem health. The EPA has designated these air pollutants as criteria air pollutants and listed these chemicals as toxic because of their harmful effects on human and ecosystem health. The measure for water pollution, biological oxygen demand (BOD), indicates the extent to which oxygen is depleted and hence the impairment of the ability of that water system to sustain aerobic life. The total suspended solids measure for water pollution indicates the extent to which that water is turbid, the greater turbidity reduces the penetration of sunlight into the waterbody and thus the ability of that water body to support photosynthetic life and thus life along the food-chain. Although the IPPI project examined the population of US firms, it reports a number of 'missing values' for several industries for water and metal pollution intensities as a result of the Census' disclosure rules (Wheeler, pers. comm.).

One monetary measure for pollution intensity is included i.e. the share of pollution abatement operating costs to the value-added in that industry for the year 1989. The pollution abatement operating costs include payments to treat or to dispose of air, water and solid waste, but exclude capital expenditure. The injury rates are the number of cases of occupational injury recorded in an industry per 1000 employees for the year 1989.

5. ESTIMATION MODEL

The regression model examines the intensity of net US imports from Mexico between the pre-NAFTA and the post-NAFTA years to see if these net import shares show greater growth in the more polluting or injurious industries than in the less polluting or injurious industries. I run two separate regressions, the first compares the pre-NAFTA years (1991-3) with the years immediately following NAFTA (1994-6) while the second compares the pre-NAFTA years with the period several years after NAFTA (1997-9). I examine these two different post-NAFTA periods because trade may expand significantly only several years after NAFTA takes effect as a result of the time required to set up production and import or export ties.

The observations are for 4-digit SIC industries for the years 1991-9. The dependent variable is the ratio of US net imports from Mexico to US domestic production. This ratio is used to indicate the extent to which a given industry has located its production in Mexico (Levinson and Taylor, 2001). The NAFTA dummy takes the value 1 for the period when NAFTA is in effect. This coefficient on the NAFTA variable captures the average growth of industries during the transition from the pre to the post NAFTA period. The 4-digit SIC industry dummies control for inter-industry differences in the pre-NAFTA net import levels. The explanatory variables of interest are the interaction variables: (1) the interaction of injury rates variable with the NAFTA dummy and (2) the interaction of the various measures of pollution intensity with the NAFTA dummy. These variables capture the growth rate of the more polluting (or injurious) industries relative to that of the less polluting (or injurious) industries during the transition period between the pre-NAFTA and the post-NAFTA years.

I estimate two different models. The first specification simply compares the growth of the more polluting industries relative to the less polluting industries during the transition from pre to post NAFTA years. The first estimated model is as follows:

$$Y_{i,t} = I_i \ \beta_1 + N_{i,t} \beta_2 \ + P_i \times N_{i,t} \beta_3 + \varepsilon_{i,t} \qquad \text{[Model 1]}$$

where Y is ratio of US net imports from Mexico to US domestic production; I is the vector of industry dummies; N is the NAFTA dummy that takes the value 1 for the years during which NAFTA is in effect, and 0 otherwise; and P is the vector of measures of physical pollution intensity (measured for 1987), shares of pollution abatement costs (measured for 1989) and injury rates (measured for 1989). The observations are for industry i at time t.

The second specification adds further controls to allow for industries that are more intensive in physical capital (or human capital) to grow at different rates relative to industries that are less intensive in physical capital (or human capital). These control variables are the interaction of dummies of centiles of physical capital intensity with the NAFTA dummy and the interaction of dummies for centiles of human capital intensity with the NAFTA dummy. Dummy variables for centiles of physical capital intensity indicate ten different centiles of physical capital intensity. The physical capital intensity of an industry is the ratio of the payment to physical capital to the industry's value-added. The human capital intensity variables are defined analogously. The payment to physical capital is the difference between value-added and payroll expenses (Grossman and Krueger, 1993). The payment to human capital is the share of the payroll paid to labor with more than high school education (Grossman and Krueger, 1993). I assume payments to unskilled labor is the multiple of the number of employees and the wages of workers with less than high school education. I also assume these workers work 2000 hours annually. The estimated model is as follows:

$$Y_{i,t} = I_i \; \beta_1 + N_{i,t}\, \beta_2 \; + P_i \times N_{i,t}\, \beta_3 + X_i \times N_{i,t} \; \beta_4 + \varepsilon_{i,t} \qquad \text{[Model 2]}$$

where X is the vector of dummies indicating 9 different centiles of human capital intensity and 9 different centiles of physical capital intensity (measured for 1991) and the other variables are defined as in Model 1. The observations are for industry i at time t. The null hypothesis is that Mexico does not specialize in the more polluting industries i.e. $\beta_3 = 0$. If Mexico does specialize in the more polluting industries, β_3 would be positive and the null would be rejected.

6. POLLUTION AND INJURY RANKING ACROSS INDUSTRIES

Several patterns emerge in the pollution rankings based on US manufacturing industries. The top 25 polluting industries generally produce a large amount of pollution per dollar value-added, while the rest of the industries produce far less. This fact would suggest that only a few industries may consider the differences in pollution abatement costs among sites as a crucial variable in their location decision. Charts 1-4 show the top 25 polluting industries ranked by their toxic, air, metal and water pollution intensities. The top 25 polluting industries in toxic pollution generate between 213 to 8 g of toxic pollutants per dollar value-added, while the rest of the industries produce a mean of only 1 g per dollar value-added. Similarly, the top 25 industries in air pollution generate between 281 to 45 g of air pollution per dollar value-added, while the rest of the industries produce a mean of only 3 g per dollar value-added. The figures for water pollution (measured by BOD) are between .10 and .0009 g per dollar value-added for the top 25 industries and .00005 g per dollar value-added for the rest of the industries. Unsurprisingly, the emissions are even more skewed for metal pollution intensity as only a subset of industries use metals. The top 5 polluting industries generate between 198 and 5 g per dollar value-added, while the rest of the industries produce a mean of only .22 g per dollar value-added.

As the emission of pollutants is industry-specific and these emissions cover a diverse set of pollutants, it is difficult to construct a single index of polluting industries. Thus I include the various measures of pollution intensity in the estimations. Using any single measure of pollution intensity would not provide the complete picture of the pollution content of US net import intensity, as many industries that rank highly on some types of pollution intensities do not rank highly on other measures. Table 2a reveals that only 10 industries rank among the top 25 industries in both toxic and air pollution intensity, while only 22 industries rank among the top 50 in both toxic and air pollution intensity. When the consideration is expanded to water pollution intensities as well, table 2b shows only 3 industries rank in the top 25 of all three air, toxic and water pollution intensity measures and only 8 industries rank in the top 50. A comparison of tables 2a and 2b reveals that 6 out of the 10 industries that rank in the top 25 of toxic and air pollution intensity do not rank within the top 50 industries for all three toxic, water and air pollution intensities.

There is considerable diversity within a given class of pollution intensity measure. A priori the correlation between various measures of pollutants is unclear. Pollutants released in the manufacturing processes may be complements or substitutes. The media into which pollutants are released - air, water and land - may be substitutes or complements. Table 2c reveals that the correlation is high (.65) between toxic materials released to air and that released as solids but that correlation is low (.23) between toxic materials released to air and that released to water. The correlation is high (.70) among the two measures of water pollution, TSS and BOD. The correlation is high among some criteria air pollutants (SO_2, NO_2 and PM) but is weaker among other air pollutants.

It would be interesting to compare the industry's direct contribution to physical pollution with its indirect contribution through its energy consumption. Table 2c suggests that the energy intensity bears a strong relationship with only a few of the physical pollution measures (i.e. air pollution intensity). This observation suggests that industries that may look environmentally benign from their measures of physical pollution intensity may in fact be not so benign when their indirect contribution to pollution through energy consumption is taken into account. Thus looking separately at the relationship between energy intensity measures and net import shares would be useful. Nevertheless, Chart 5 reveals that the energy intensity across industries share the characteristic of pollution intensity patterns in that industries that rank at the top of the energy intensity rank are significantly more energy intensive than the rest of the industries. However, the differences between the top 25 and the rest of the industries are less pronounced with the mean for the top 25 differing from the mean for the rest of the industries by only 5-fold. The mean for the energy cost as a share of value-added for the top 25 industries is .29 while the mean for the rest of the industries is .04.

Unlike pollution intensities that are concentrated in the top few industries, injury rates are more evenly distributed across industries. Chart 6 shows that the top 25 industries experience 2-2.5 times the mean injury rates within the manufacturing sector. The final measurement of interest is the share of pollution abatement operating costs. Chart 7 shows that like the patterns of physical pollution intensity, the share of pollution abatement operating costs is concentrated in the top few industries. The share for the top 25 industries averages about .058, about 60-fold greater than the mean for the rest of the industries.

7. TRENDS IN THE NET IMPORT INTENSITY FOR THE POLLUTING INDUSTRIES

The intensity of US net imports from Mexico in the more polluting industries between 1987-1999 can be seen in Charts 8-19. These charts indicate that between 1991-1999, the net import intensity peaks in 1992 and 1995, the latter attributable in part to the November 1994 peso devaluation. The analysis below compares the net import intensity in 1993-4 with that in 1996-9.

First, I consider all polluting industries including those that are capital intensive. Trade-related compositional changes in Mexico's production result from the decisions of firms in polluting industries to locate in Mexico as well as the decisions of existing polluting firms in the US to relocate to Mexico. Only the decisions of the existing firms to relocate would be influenced negatively by sunk physical capital. Charts 8-13 reveal that the US exports goods in these industries to Mexico and not vice versa. Charts 8-11 indicate no clear increase in the net import intensity between 1993-4 and 1996-9 for the top 25 polluting industries in toxic, air and water pollution intensities or for the top 25 industries in the shares of pollution abatement operating costs. Chart 12 and 13 show some increase in the net import intensity for the top 25 industries in metal pollution intensity and injury rates. Nevertheless, the US continues to export goods in these industries to Mexico both in 1993-4 and 1996-9. In contrast, as seen in Charts 8-13, the net import intensity for the industries other than the top polluting industries in the respective pollution intensity measures show an even greater increase, with the US exporting the goods to Mexico in 1993-4 but importing these goods from Mexico in 1996-9.

Next, I consider industries that are among the top 50 polluting industries and whose physical capital intensity is below the mean. Chart 14 reveals that the net import intensity show an increase in only one measure of pollution intensity i.e. air pollution intensity. The US moved from exporting these goods to Mexico in 1993-4 to importing these goods between 1996-9. Nevertheless, the net import intensity for these industries has fallen between 1995 and 1999. For other measures of pollution intensity, the US exported goods in these industries to Mexico in 1993-4 and 1996-9. Chart 15 shows that the net import intensity in the more injurious industries increased slightly between these two periods. However, the US continues to export injury intensive goods to Mexico in both periods. As seen in Charts 16-19, for air, metal and toxic pollution intensity and the shares of pollution abatement costs, the net import intensity has remained similar in both of these two periods.

8. REGRESSION RESULTS

Tables 5 and 6 report the results from the estimation of Model 1 and Model 2, respectively. In both tables, columns (1) and (2) report the results for the comparison between the pre-NAFTA years (1991-3) and the immediate post-NAFTA years (1994-6). Columns (3) and (4) report the results for the comparison between the pre-NAFTA years and the later post-NAFTA years (1997-9). Columns (1) and (3) include only two measures of pollution intensity i.e. air and toxic pollution intensity. Columns (2) and (4) includes additional measures of metal and water pollution intensity because the many missing values for water and metal pollution intensities reduce the number of industries examined by about 40%.

I do not find strong evidence to suggest that the net import intensity has shown greater growth in the more polluting or injurious industries relative to the less polluting or injurious ones. Tables 5 and 6 reveal that for most of the coefficients of pollution intensity, the estimated coefficients are not statistically different from zero. For one measure of pollution intensity, carbon monoxide intensity, the estimates are positive in all specifications but the effects are small. Tables 5 columns 1 and 2 and Table 6 columns 1 and 2 indicate that the estimated coefficients are statistically significant above the .10% level for the two specifications that compares the pre-NAFTA years with the years immediately following NAFTA. However, according to Table 6 column 1, an increase in carbon monoxide intensity by its mean value raises the net import intensity by only .0011.[6] This is a small effect i.e. about 5% when it is compared to the average within industry increase in net import intensity of .022 between 1991-3 and 1994-7.

For toxics released as solids, the estimates are not statistically significant. Although the point estimates are positive, even if these estimates had been statistically significant, the size of the effect would be small. As seen in Table 6 column 3, an increase of the intensity of toxics released as solids by its mean value would raise net import intensity by only .0029.[7] This is a small effect i.e. about 3% when it is compared with the average within industry increase in net import intensity of .093 between 1991-3 and 1997-9. For other coefficients that are statistically significant, the signs are negative. Table 6 column 2 indicates that between 1991-3 and 1994-6, net import intensity grew more in industries with smaller shares of pollution abatement costs. The point estimates for injury rates are also negative. One concern with these results is that the pollution measures that are available no finer than at the 4-digit SIC level enable only imprecise estimates of the coefficients on the pollution measures. Nevertheless, as seen in Tables 5 and 6, for many measures of pollution intensity, other than carbon monoxide and toxics released as solids, the point estimates are negative. Thus narrower standard errors would not reverse the conclusion that the net import intensity has not shown greater growth in the more polluting or injurious industries.

9. OTHER ISSUES: AMBIENT AIR POLLUTION IN MEXICAN CITIES

Although this paper focuses on the influence of trade on the composition of manufacturing industries in Mexico, it would be interesting to know the ambient pollution levels in Mexico's manufacturing cities as they affect human health. Some environmentalists oppose NAFTA on the grounds that the NAFTA-related expansion in the level of production, without

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[6] This figure is the product of the coefficient on carbon monoxide intensity and the mean carbon monoxide intensity in all industries i.e. .00023 × 4.8.
[7] This figure is the product of the coefficient on the intensity of toxics released as solids and the mean intensity of toxics released as solids i.e. .0012 × 2.4.

significant investments in the environmental infrastructure particularly in the Mexican border region, would worsen the environmental quality in this area (US Trade Representative, 1992). At present, centralized data is available only for air pollution levels, even though water and toxic pollution are two other important environmental issues in the border region. Using the available data on air pollution, this section describes the air pollution levels in these cities. This study cannot isolate the effect of NAFTA on the ambient air pollution in these border cities because it is difficult to construct the counterfactual emission levels if NAFTA did not come into force. Ambient air pollution levels capture both emissions from the manufacturing sector and from vehicles, with vehicular emissions tending to increase even if NAFTA did not take effect.

The EPA's Aerometric Information Retrieval System (AIRS) provides the only standardized air pollution data for several Mexican border cities. The data, tabulated in Table 7-9, indicate the number of violations in the air quality standards i.e. the number of observations that exceed the US air quality standard.[8] Only few monitoring stations have operated both before and after NAFTA. Data from these stations, i.e. Ciudad Juarez stations 1 and 2, tabulated in Table 7 and 8, columns 1 and 2, do not indicate radical growth in air pollution levels between the pre-NAFTA and post-NAFTA periods. However, one concern with these stations is that they may be located in the cleaner parts of the city and thus they may underestimate the average level of pollution in these cities both before and after NAFTA. For example, Table 8 columns 1-3 reveal that the older stations in Ciudad Juarez, i.e. stations 1 and 2, show lower carbon monoxide levels in the most recent years than the new station in that city, i.e. station 3. Indeed Ciudad Juarez station 1 is at a technical institute where the ambient air pollution is likely to be lower than that in the industrial zones of Ciudad Juarez.

Table 7 and 8 indicate that during the post-NAFTA period, border cities experience violations of the carbon monoxide and the ozone standards. The monitoring stations in Mexicali show large numbers of violations.[9] The monitoring stations in Tijuana and Ciudad Juarez show fewer violations, though station 3 in Ciudad Juarez shows a large number of violations for carbon monoxide and station 2 in Tijuana shows a large number of violations for ozone. Table 9 shows that none of the stations show violations of the sulphur dioxide standard. None of the stations

[8]The Mexican air quality standards for these pollutants are similar to the US standards (US EPA – SME, 1997).
[9] The standards are set whereby a violation indicates that the ambient concentration adversely affects the health of the population.

show violations for lead concentrations in the air. However, the lead data may not provide a complete view of lead concentrations in the air as only few observations are recorded annually, i.e. only an average of 37 observations in a year in a given site.

10. DISCUSSION AND POLICY IMPLICATIONS

Examining the shares of US net imports from Mexico between the pre-NAFTA and post-NAFTA periods, I do not find strong evidence of greater growth in these shares in the more polluting or injurious industries than in the less polluting or injurious industries. Using measures of physical pollution intensity that are presently available at a resolution no finer than the 4-digit SIC level, I am unable to reject the null hypothesis that the coefficients on most of the pollution intensity variables and the injury rates variable are not significantly different from zero. For only one measure of pollution intensity, i.e. carbon monoxide intensity, I find a positive and statistically significant coefficient, indicating that net import intensity grew faster in those industries that are more intensive in carbon monoxide. However, the effect of carbon monoxide intensity on the shares of US net imports from Mexico is small. I also examine the trends in US net import intensity for the top polluting and injurious industries, both including and excluding those that are intensive in physical capital. For most measures of pollution intensity and injury rates, the US exports goods in these industries to Mexico and not vice versa both in the pre and post-NAFTA periods examined. Only for those industries that are both among the top polluting industries in air pollution intensity and that are less intensive in physical capital, the US imports these goods from Mexico between 1996-9. Nevertheless, even for these industries, the net import intensity has shown a decline between 1996 and 1999.

The lack of strong evidence that Mexico has specialized in polluting industries corresponds with the facts on the distribution of pollution intensity across industries. Only few industries appear to have significant physical pollution intensity and shares of pollution abatement costs and thus only a few industries are likely to consider pollution costs as a significant factor in their location decisions. Further work should examine in more detail the changes in net import intensity in industries that are intensive in carbon monoxide emissions. It is important to understand whether the growth in the net imports (or the contraction in US domestic production) in one or two dominant industries is responsible for this effect and whether changes in these few industries can be in turn explained by factors other than Mexico's comparative advantage in industries that are more intensive in carbon monoxide.

Nevertheless, there are some limitations to the study that may lead to the failure to detect Mexico's specialization in polluting industries even if such were the case. The 4-digit SIC measures for pollution intensity may still be too aggregated. The potential aggregation of the more polluting sub-industries with less polluting ones reduces the power in the regression analysis to detect Mexico's specialization in polluting industries. The use of physical pollution intensity in 1987 to measure the pollution intensity of an industry could have led to the mislabelling of the more polluting industries as clean if by 1987 that industry had shifted the most polluting sub-industries or the most polluting stages of production to sites outside the US.

Because the failure to detect Mexico's specialization in polluting industries may have arisen from limitations in the empirical study, it is worth considering the potential policy responses to ensure that economic inefficiency does not arise if Mexico specializes in the more polluting or injurious industries. If Mexicans chose to specialize in such production based on full information, the economic outcome simply reflects their choice of balancing the gains from production and the costs to their environment and health. Mechanisms that provide information to Mexicans on the pollution emitted into their environment and that allow Mexicans to register their preferences on how they wish to strike this balance are therefore important for public policy. Policy changes suggested below can enhance the availability of these mechanisms for Mexicans.

Mexico has developed several information databases that if made public could greatly improve the public's knowledge of firms' emissions and PROFEPA's enforcement of environmental laws. Mexico has implemented the Environmental Compliance Indicators project in which the PROFEPA rates firms' environmental compliance on a 1 to 100 scale, as well as the Environmental Enforcement and Tracking System in the Mexico City Metropolitan Area that tracks the corrective measures ordered by the PROFEPA and the violators' compliance record (PROFEPA, 2000). It is also developing a database that tracks all legal and administrative cases handled by the PROFEPA's Legal Office (PROFEPA, 2000), including the subject matter involved and the decisions reached. The 1996 revised LGEEPA states that everyone is entitled to environmental information, except information that is only relevant to its owner (PROFEPA, 2000). Because firms release their waste into publicly owned air and water resources, the public has an interest in understanding these emission levels and the environmental agency's activities. Mexico has shown its willingness to make environmental information public, for example, by developing a public database on firms' toxic pollutant releases (a database akin to the Toxic Release Inventory in the US) under the North American Pollution Transfer and Release Database project (EPA, 2001) and by providing summaries of some of its enforcement actions in its PROFEPA report (PROFEPA, 2000).

Mexicans can submit complaints about firms that pollute and about their government's failure to enforce environmental laws directly to the PROFEPA (PROFEPA, 2000). Nevertheless, as a result of the shortage of resources, PROFEPA has been able to respond to only a fraction of the citizens complaints received. In 1995-7, it addressed 64% of the petitions received in 1992-7[10] (PROFEPA, 2000). Mexicans can also submit complaints about their government's failure to enforce domestic environmental laws to the CEC (Hufbauer et al, 2000). However, the removal of several provisions in this complaint process would improve public dissemination of information and encourage the investigation of all legitimate complaints (Hufbauer et at, 2000).[11] At present, firms have also used the NAFTA dispute resolution mechanism, i.e., the Chapter 11 provisions, to challenge national governments in the country of investment that are alleged to breach NAFTA rules (De Palma, 2001). While some environmentalists claim that the NAFTA tribunal's Chapter 11 decisions have reduced environmental protection (De Palma, 2001), other commentators argue that these decisions have been based on legal principles of equal treatment of domestic and foreign investors and scientific basis for environmental laws (Hufbauer et al, 2000). The public will be able to evaluate these competing views of the effects of Chapter 11 if the tribunal's proceedings are made public.[12]

The question is how transferable are these results on the NAFTA-related trade expansion to the anticipated trade expansion under the proposed FTAA. The gaps in environmental protection and thus environmental compliance costs between the US and lower-income Latin American countries are much larger than those between the US and Mexico. Thus it remains an

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[10]Of the 11,069 petitions processed in 1995-7, PROFEPA resolved 53% of the cases, found that 16% had no legal basis and 16% had no violations, and that 13% were outside its competency (PROFEPA, 2000).
[11]At present, the CEC does not investigate the facts behind a complaint, even if the complaint is legitimate, unless two-thirds of its members agree to this investigation (Hufbauer et al, 2000). The CEC publicizes the facts they gather about the complaint only if two-thirds of its members agree to this (Hufbauer et al, 2000).
[12]Only recently, the tribunal has accepted written briefs from third parties. The NAFTA proceedings have never been opened to the public (De Palma, 2001).

open question whether these gaps between the US and lower-income Latin American countries are large enough to counter other production considerations to result in the location of the more polluting industries in Latin America. To ensure the trade-off between production and pollution reflect public preference, the public in these Latin American countries need information on pollution emissions and mechanisms that register their preferences, but both are scarce.

This analysis focuses on only one aspect of influence of trade i.e. its effect on the composition of goods produced.[13] It would be interesting to analyse the trends in the adoption of environmental technologies in Mexican industries between the pre-NAFTA and the post-NAFTA years. Pro-trade advocates argue that the reduction in import barriers and increased foreign investment that accompany trade liberalization would increase the adoption of environmental technologies. Future work will attempt to examine the trend of Mexican imports in pollution abatement equipment. Unfortunately, at present, it is difficult to obtain firm level data on the imports of pollution abatement equipment and to discern the goods specifically used for pollution abatement from the data on US exports to Mexico.

[13]Trade also influences the income-related demand for environmental quality. Because trade liberalization raises the income for some Mexicans and reduces that of other Mexicans, the net effect on the demand for environmental quality is unclear. Moreover, the increase in the demand for environmental quality among the richer may result in either better overall environmental quality in Mexico or the shifting of pollutants to other parts of Mexico where the population are less able to pay to maintain environmental quality or to keep out polluting activities.

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Personal communication

Dr. David Wheeler, Policy Research Division Environment and Infrastructure, World Bank

Table 1: Industries that rank in the top 25 for both toxic and air pollution intensity

Industry	Rank for Toxic pollution intensity	Toxic intensity (g/$)	Rank for air pollution Intensity	Air pollution intensity (g/$)
Nitrogenous fertilizers	3	137.2	8	132.8
Inorganic pigments	6	71.5	17	68.3
Alkalis & chlorine	7	54.8	19	62.7
Pulp mills	12	23.7	6	176.3
Electrometallurgical	14	22.4	11	124.8
Industrial inorganic chemicals	18	13.5	23	48.0
Secondary non-ferrous metals	19	13.1	12	111.4
Petroleum refining	22	12.2	10	129.5
Steel mills	23	9.9	14	95.5
Gum & wood	25	8.8	4	240.9
Mean for all industries		3.7		10.1
Number of industries with pollution information	437		451	

Table 2: Industries that rank highly among physical measures of pollution intensity

Industry	Rank by toxic pollution intensity	Toxic pollution intensity (g/$)	Rank by air pollution intensity	Air pollution intensity (g/$)	Rank by water pollution intensity	Water pollution intensity (g/$)	Rank by share of PAOC	Share of PAOC	Rank by energy intensity	Energy intensity
Pulp mills*#§	12	23.7	6	176.3	2	.059	19	.041	43	0.12
Secondary non-ferrous metals*#§	19	13.2	12	111.4	1	.10	7	.061	41	0.12
Gum & wood*	25	8.8	4	240.9	15	.002	13	.047		
Industrial inorganic chemicals†#§	11	26.2	33	31.2	21	.0012			30	0.13
Petroleum refining†#§	22	12.2	10	129.5	28	.0009	2	.093	12	0.22
Plastics & Resin†	26	7.9	29	36.7	37	.0005				
Explosives†#	27	7.8	32	35.8	40	.0004	32	.037		
Cotton finishing plants†	36	5.6	39	23.4	25	.0009				
Mean for all industries		3.7		10.1		.0013		0.012		.05
Number of industries with pollution information	437		451		322		462		462	

Notes: * Industries that rank in the top 25 for all three toxic, air and water pollution intensities

† Industries that rank in the top 50 for all three toxic, air and water pollution intensities

Industries that rank in the top 50 for all four toxic, air, water pollution intensities and share of pollution abatement operating costs (PAOC)

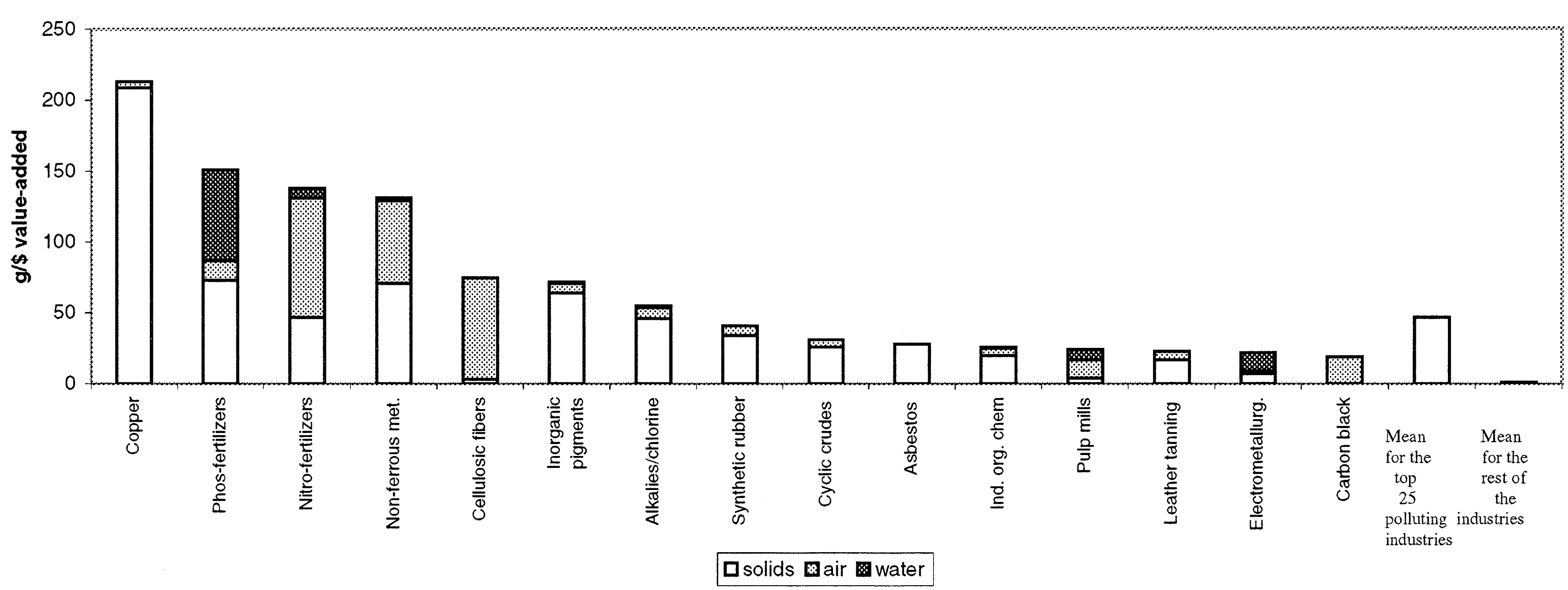
§ Industries that rank in the top 50# for all four toxic, air, water pollution intensities

Table 3: Rank correlation among various measures of pollution intensity

	Injury	PAOC	Energy	Toxic	Toxic (air)	Toxic (solids)	Toxic (water)	Metal	Metal (air)	Metal (solids)	Metal (water)	Air	Parti -culates	CO	SO2	NO2	VOC	PM 10	TSS
PAOC	-.00																		
Energy	.09	.54																	
Toxic	-.14	.45	.35																
Toxic (air)	-.09	.27	.34	.81															
Toxic (land)	-.16	.47	.33	.94	.65														
Toxic (water)	-.07	.33	.12	.65	.23	.55													
Metal	-.01	.16	.18	.53	.54	.55	.04												
Metal (air)	.04	.31	.22	.43	.41	.47	.04	.84											
Metal (solids)	-.01	.15	.18	.52	.54	.55	.04	.99	.84										
Metal (water)	-.08	.25	.10	.32	.11	.50	.02	.18	.23	.17									
Air	.05	.57	.66	.22	.25	.18	.12	.06	.13	.059	.13								
Particulate	.06	.31	.52	.06	.05	.04	.06	.01	.04	.01	.02	.69							
CO	.11	.39	.50	.16	.17	.13	.07	.10	.18	.10	.20	.78	.29						
SO2	-.01	.59	.54	.19	.16	.16	.14	.05	.12	.05	.08	.85	.54	.68					
NO2	-.00	.46	.60	.30	.38	.22	.12	.02	.02	.02	.05	.76	.67	.32	.33				
VOC	-.06	.32	.18	.18	.27	.12	.03	-.01	-.00	-.01	.02	.52	.17	.53	.56	.33			
PM-10	.00	.26	.37	-.00	.02	-.01	-.01	-.01	.01	-.01	-.01	.59	.78	.08	.05	.02	-.01		
TSS	.04	.25	.09	.08	.03	.10	.07	.13	.48	.12	.05	.19	.05	.20	.05	.04	.06	.05	
BOD	.01	.23	.08	.05	.05	.04	.04	.07	.32	.06	.05	.21	.06	.19	.10	.06	.03	.05	.70

Notes: PAOC=pollution abatement operating costs
[light shading] moderate correlation (>.50 & <.75) [dark shading] fairly strong correlation (< .75)

Chart 1: Toxic pollution intensity



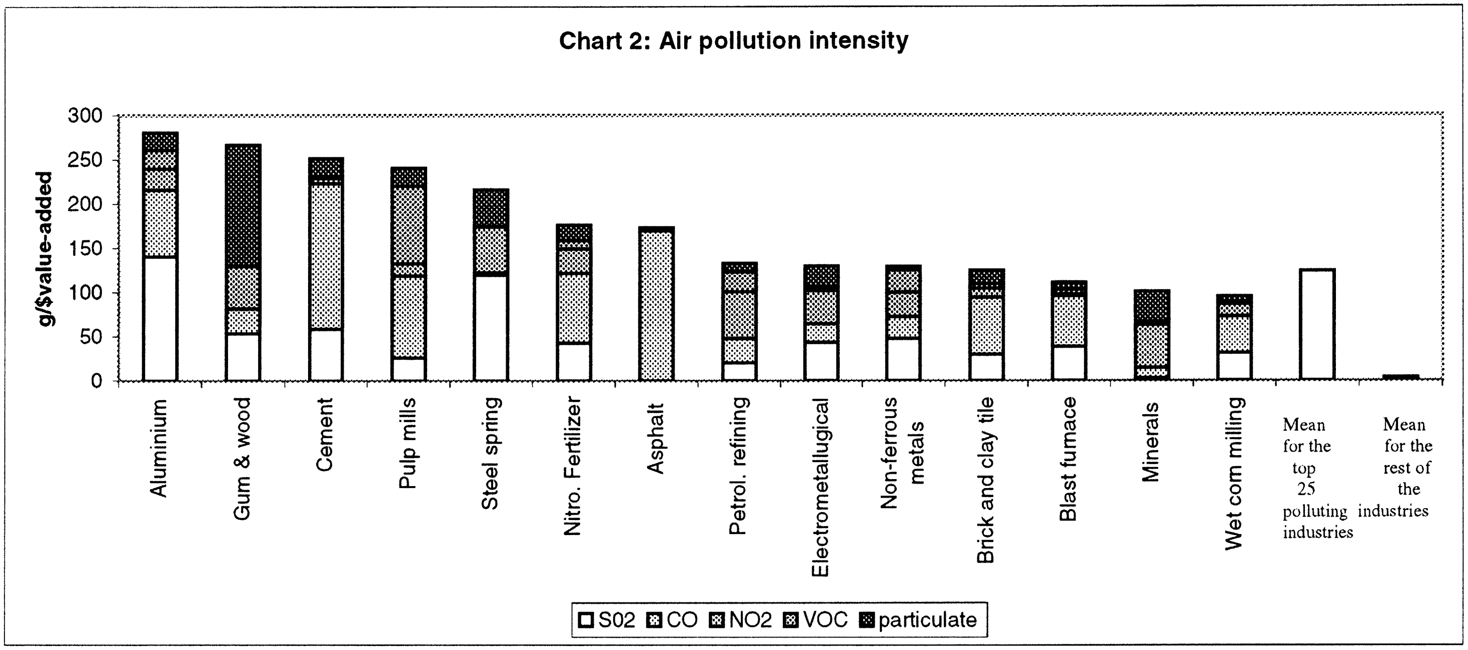


Chart 2: Air pollution intensity
g/$value-added
300
250
200
150
100
50
0
Aluminium
Gum & wood
Cement
Pulp mills
Steel spring
Nitro. Fertilizer
Asphalt
Petrol. refining
Electrometallugical
Non-ferrous metals
Brick and clay tile
Blast fumace
Minerals
Wet corn milling
Mean for the top 25 polluting industries
Mean for the rest of the industries
S02
CO
NO2
VOC
particulate

Chart 3: Metal Pollution Intensity

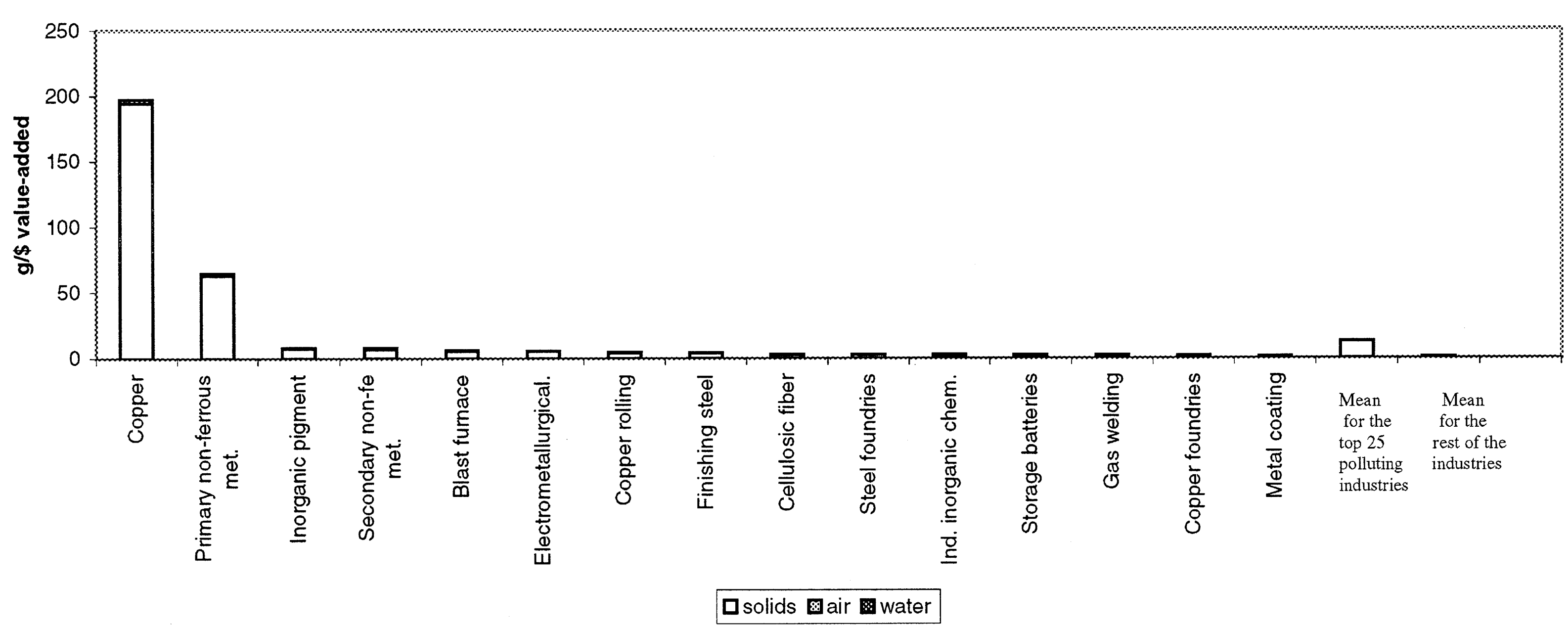


Chart 4: Water pollution intensity measured by Biological Oxygen Demand

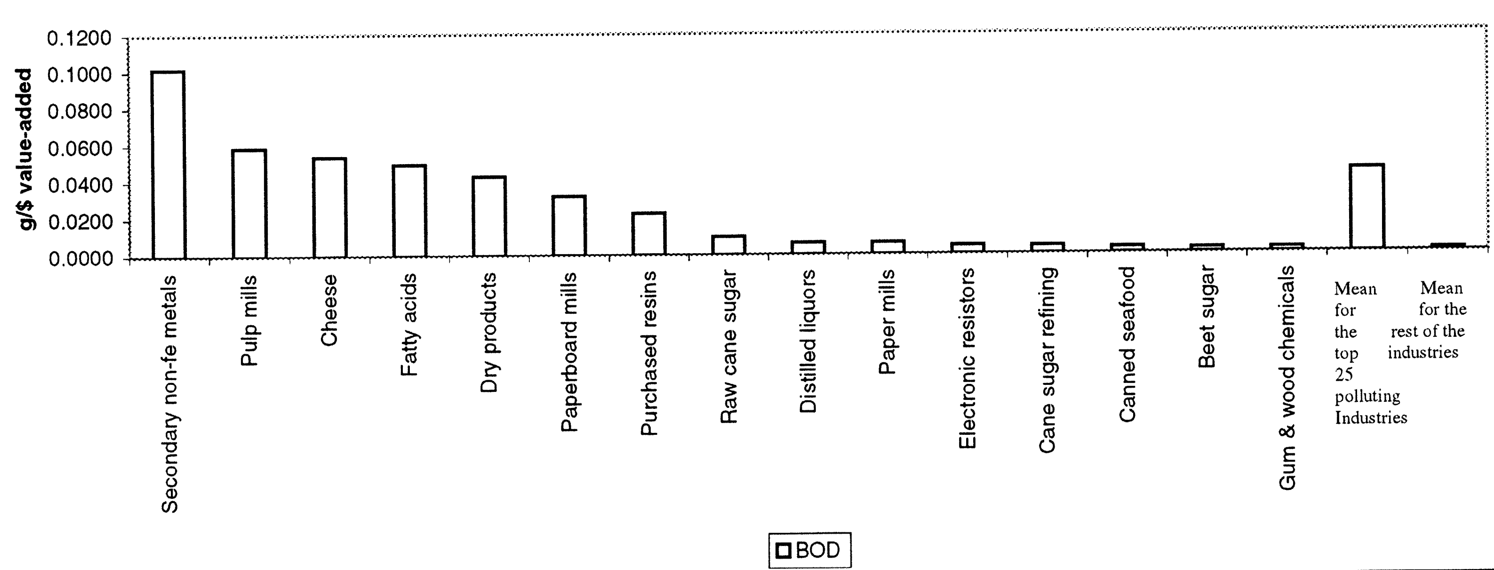


Chart 5: Energy costs as a share of value-added

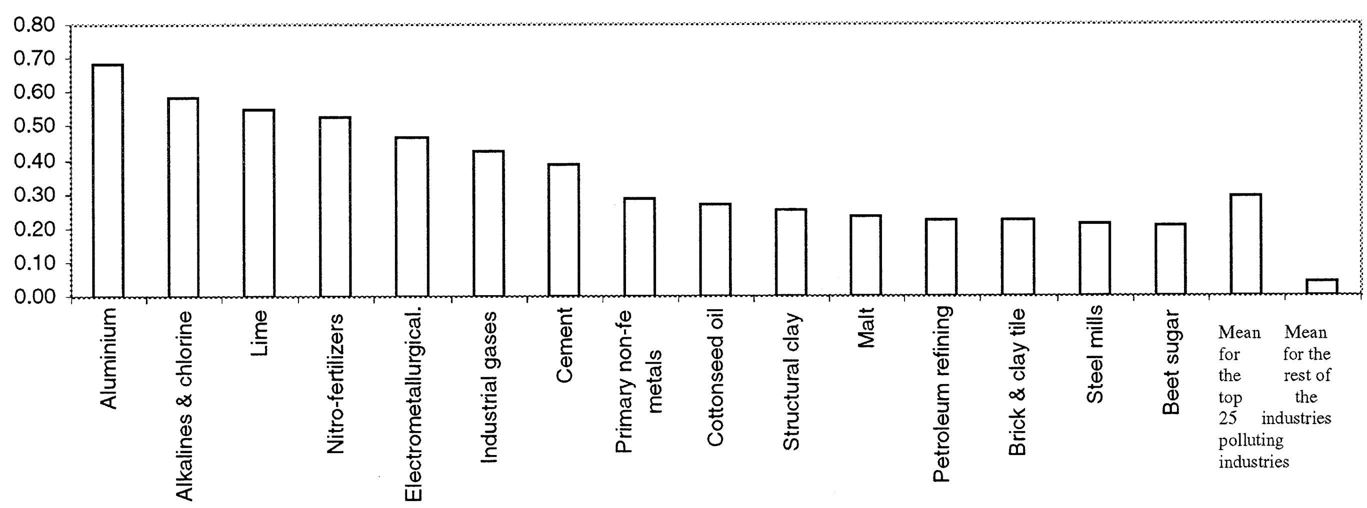
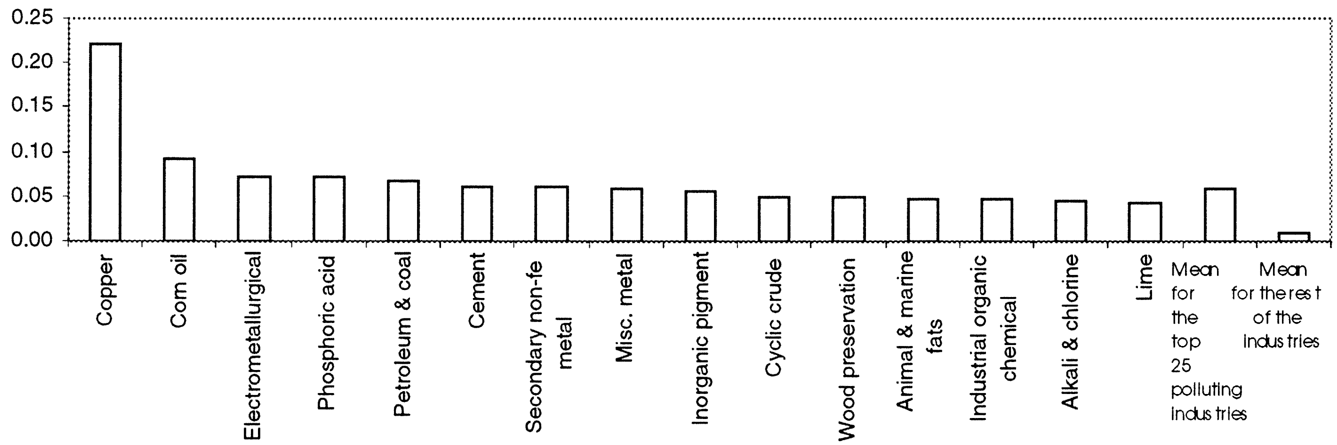


Chart 6: Share of pollution abatement operating costs



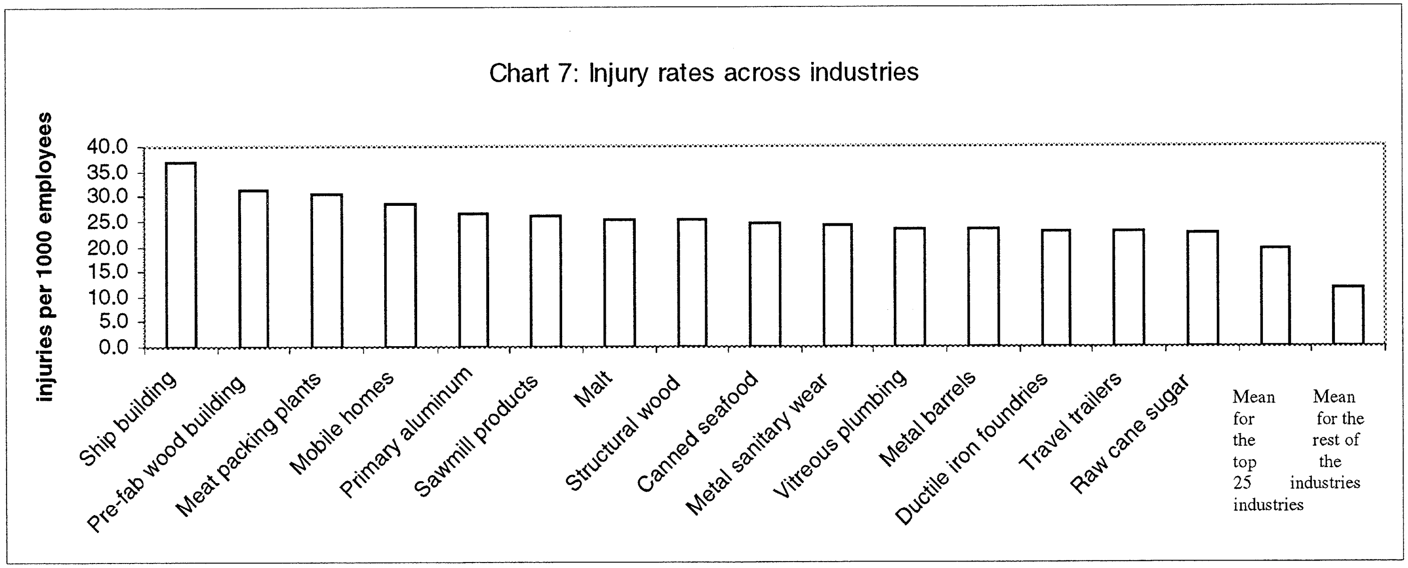


Chart 7: Injury rates across industries
injuries per 1000 employees
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Ship building
Pre-fab wood building
Meat packing plants
Mobile homes
Primary aluminum
Sawmill products
Malt
Structural wood
Canned seafood
Metal sanitary wear
Vitreous plumbing
Metal barrels
Ductile iron foundries
Travel trailers
Raw cane sugar
Mean for the top 25 industries
Mean for the rest of the industries

Chart 8: US net import intensity for the top 25 industries in toxic pollution intensity

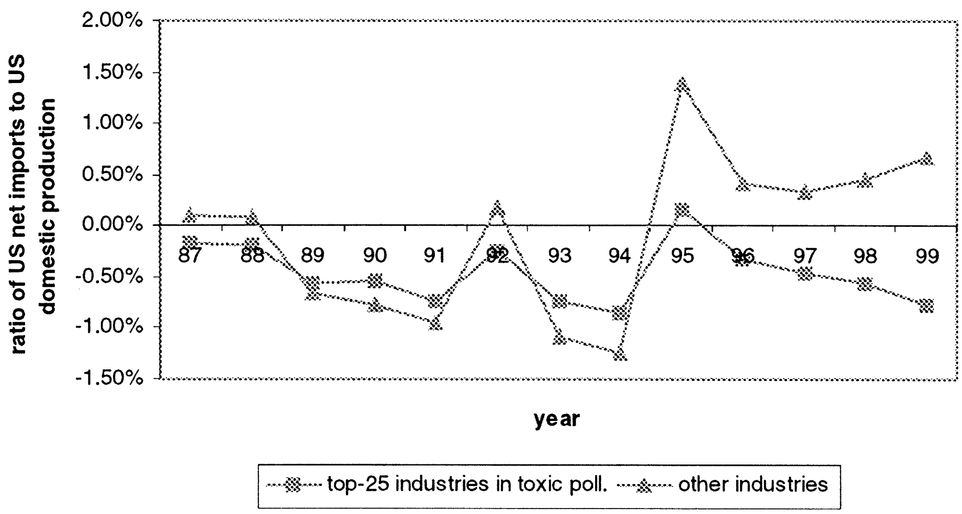
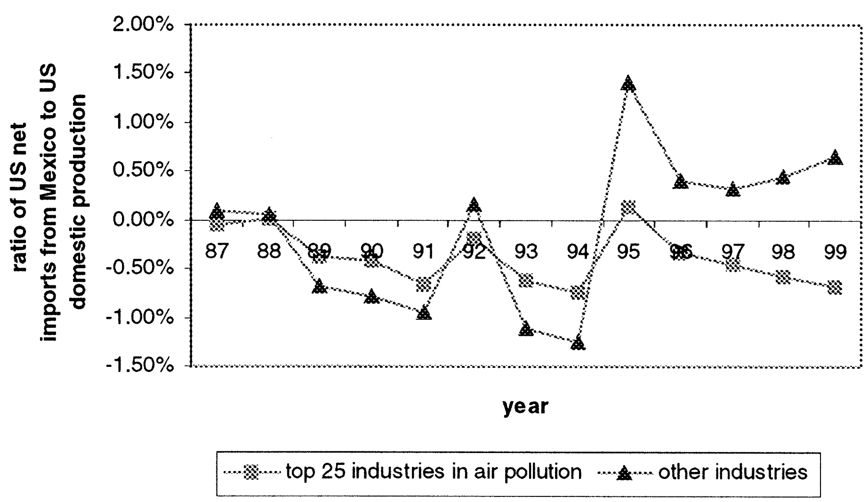


Chart 9: US net imports intensity for the top 25 industries in air pollution intensity



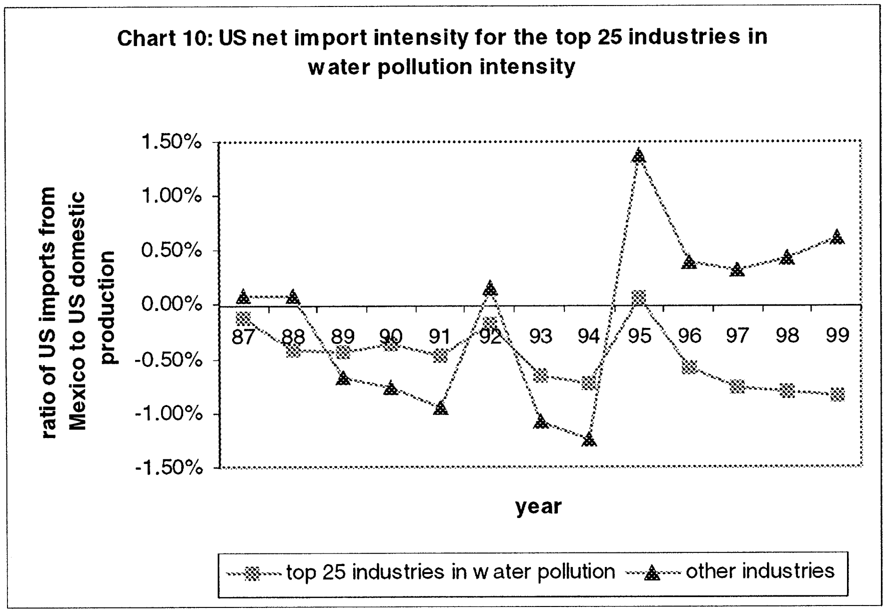


Chart 10: US net import intensity for the top 25 industries in water pollution intensity
ratio of US imports from Mexico to US domestic production
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
top 25 industries in w ater pollution
other industries

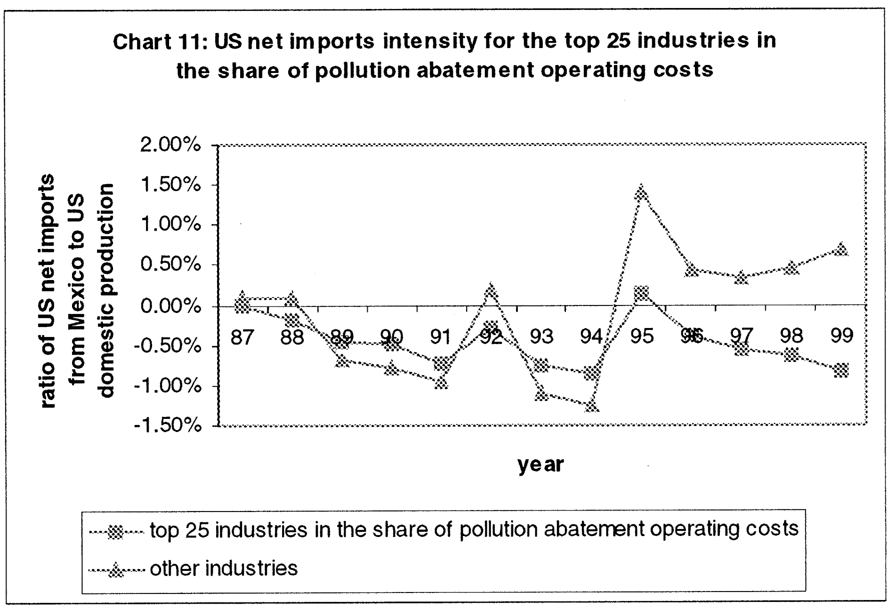


Chart 11: US net imports intensity for the top 25 industries in the share of pollution abatement operating costs
ratio of US net imports from Mexico to US domestic production
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
top 25 industries in the share of pollution abatement operating costs
other industries

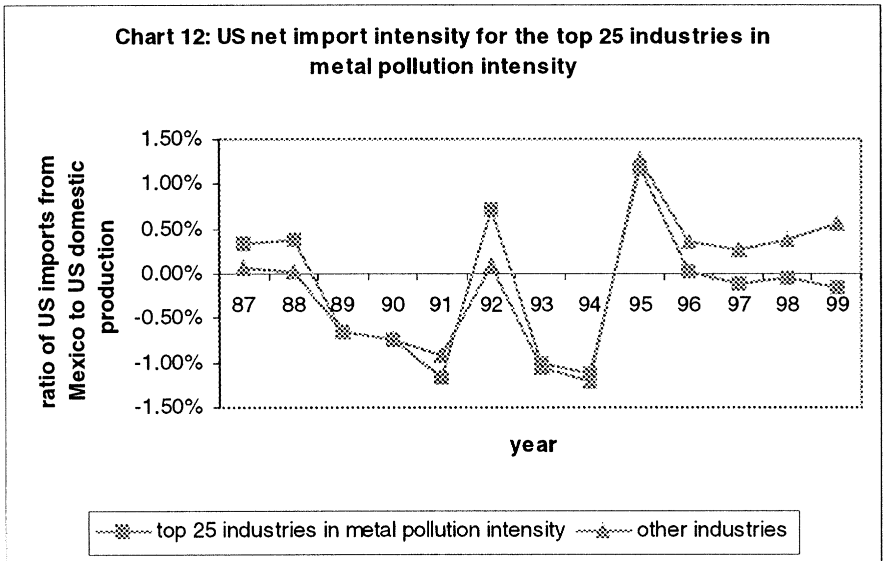


Chart 12: US net import intensity for the top 25 industries in metal pollution intensity
ratio of US imports from Mexico to US domestic production
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
top 25 industries in metal pollution intensity
other industries

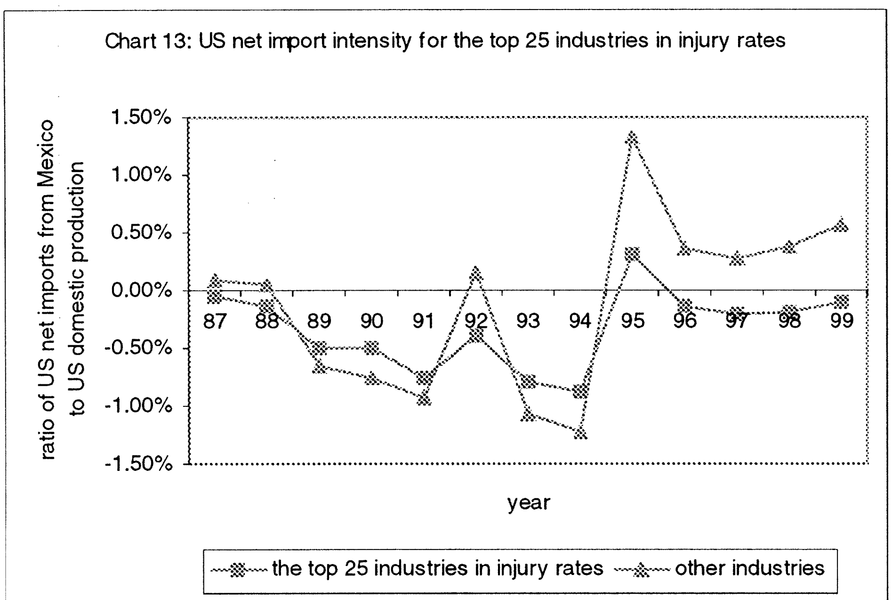


Chart 13: US net import intensity for the top 25 industries in injury rates
ratio of US net imports from Mexico to US domestic production
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
the top 25 industries in injury rates
other industries

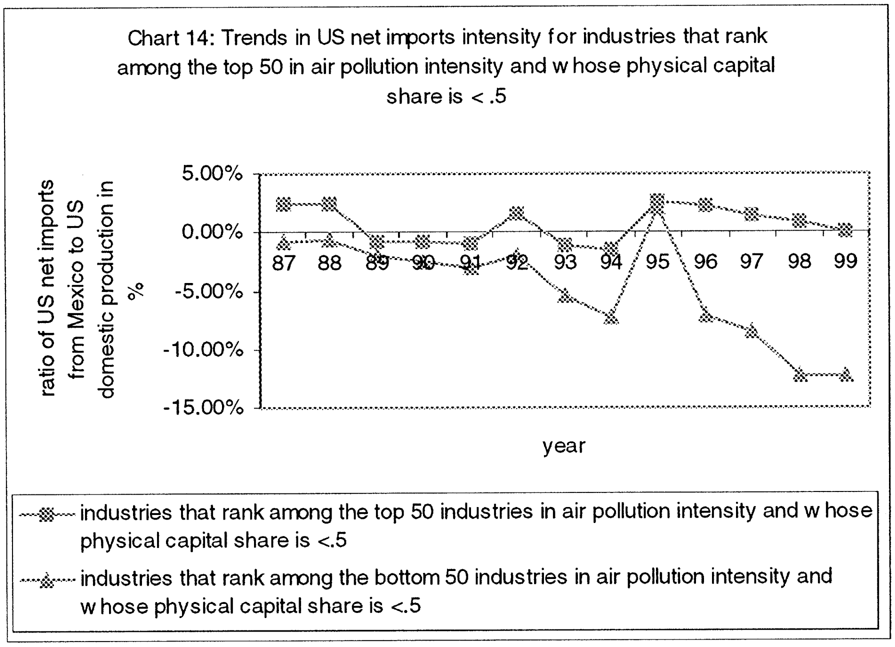


Chart 14: Trends in US net imports intensity for industries that rank among the top 50 in air pollution intensity and whose physical capital share is < .5
ratio of US net imports from Mexico to US domestic production in %
5.00%
0.00%
-5.00%
-10.00%
-15.00%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
industries that rank among the top 50 industries in air pollution intensity and whose physical capital share is <.5
industries that rank among the bottom 50 industries in air pollution intensity and whose physical capital share is <.5

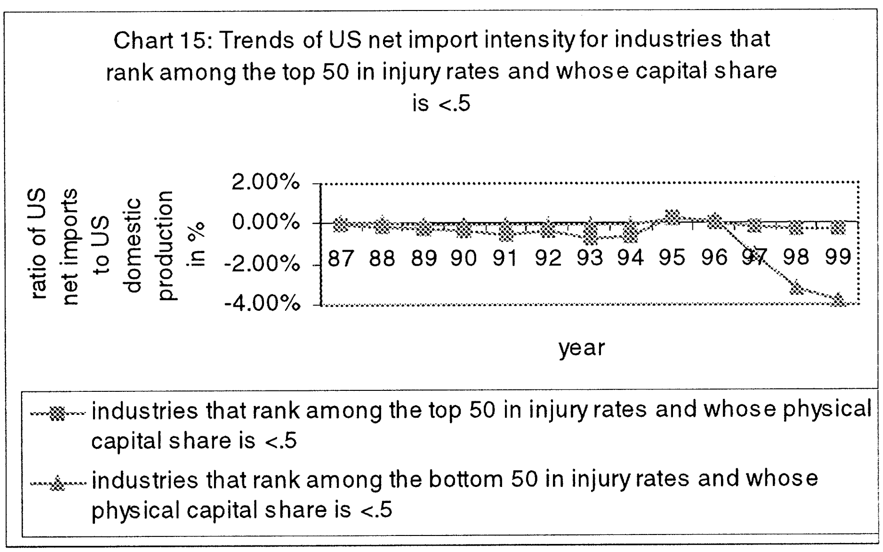


Chart 15: Trends of US net import intensity for industries that rank among the top 50 in injury rates and whose capital share is <.5
ratio of US net imports to US domestic production in %
2.00%
0.00%
-2.00%
-4.00%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
industries that rank among the top 50 in injury rates and whose physical capital share is <.5
industries that rank among the bottom 50 in injury rates and whose physical capital share is <.5

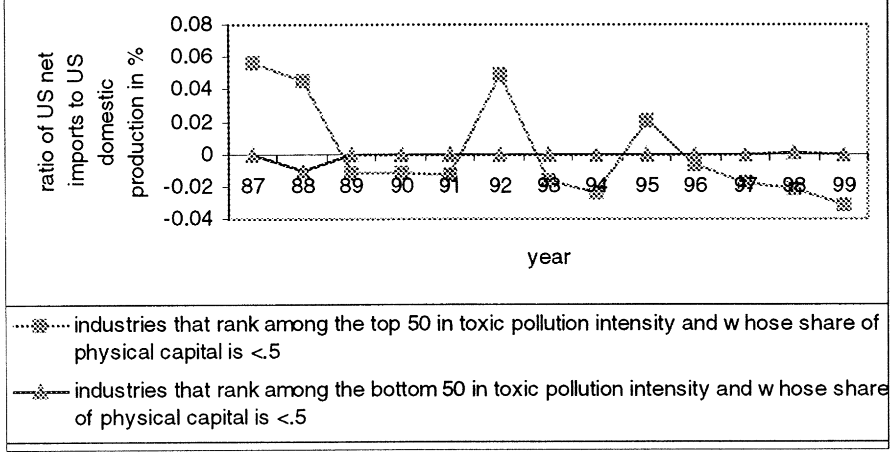


Chart 16: Trends in US net imports for industries that rank among the top 50 in toxic pollution intensity and w hose physical capital intensity share is <.5

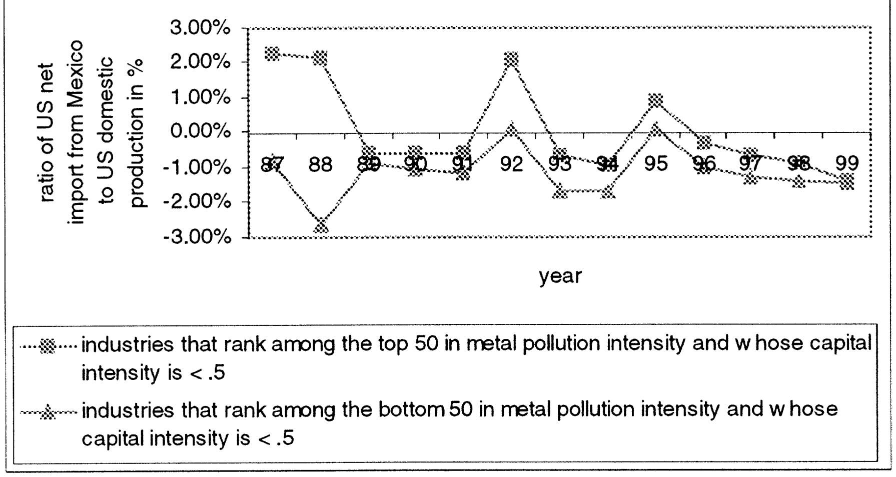


Chart 17: Trends in US net import intensity for industries that rank among the top 50 in metal pollution intensity and w hose physical capital share is < .5

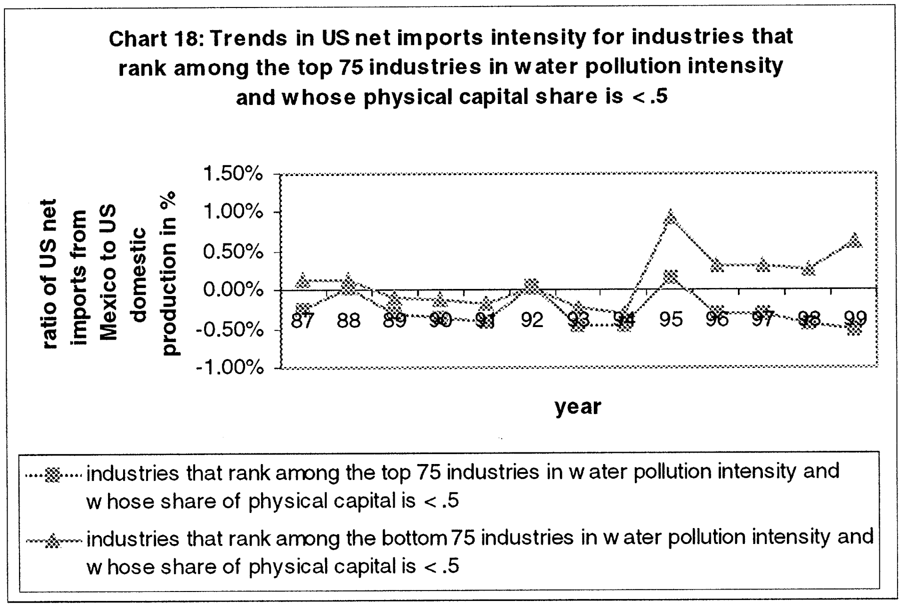


Chart 18: Trends in US net imports intensity for industries that rank among the top 75 industries in water pollution intensity and whose physical capital share is < .5
ratio of US net imports from Mexico to US domestic production in %
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
industries that rank among the top 75 industries in water pollution intensity and whose share of physical capital is < .5
industries that rank among the bottom 75 industries in water pollution intensity and whose share of physical capital is < .5

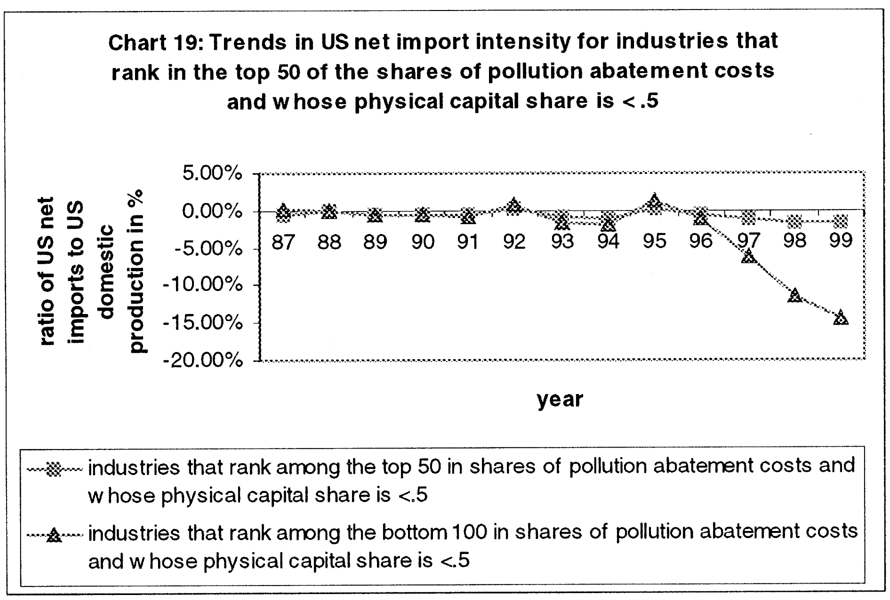


Chart 19: Trends in US net import intensity for industries that rank in the top 50 of the shares of pollution abatement costs and whose physical capital share is < .5
ratio of US net imports to US domestic production in %
5.00%
0.00%
-5.00%
-10.00%
-15.00%
-20.00%
87 88 89 90 91 92 93 94 95 96 97 98 99
year
industries that rank among the top 50 in shares of pollution abatement costs and whose physical capital share is <.5
industries that rank among the bottom 100 in shares of pollution abatement costs and whose physical capital share is <.5

Table 4: Summary Statistics

	Mean	Std. Dev.
The ratio of US net imports from Mexico to US domestic production		
in 1991-3	-.0048	.024
in 1994-6	.00065	.04
in 1997-9	-.0073	.26
Physical capital share (in 1981)	.60	.12
Human capital share (in 1981)	.17	.069
Share of pollution abatement costs (in 1989)	.014	.016
Injury rates (in 1989)	12.5	5.3
Physical pollution intensity (in 1987) in grams per dollar value added		
Air pollution intensity		
Particulate matter	2.36	10.2
Carbon monoxide	4.83	19.1
Sulphur dioxide	4.34	14.6
Nitrogen oxide	2.73	7.85
Volatile organic compounds	1.99	6.54
Particulate matter	1.28	9.09
Toxic pollution intensity		
Toxic released to air	1.67	6.68
Toxic released to water	.45	4.23
Toxic released as solids	2.44	9.05
Metal pollution intensity		
Metal released to air	.022	.10
Metal released to water	.0035	.027
Metal released as solids	.56	4.13
Water pollution intensity		
Biological oxygen demand	.0014	.0089
Total suspended solids	.012	.10

Table 5: OLS estimates of the determinants of US net imports from Mexico pre-NAFTA and post-NAFTA

	(1)	(2)	(3)	(4)
Post-NAFTA years	1994-6	1994-6	1997-9	1997-9
Pollution measures	Air & toxic	All	Air & toxic	All
Dependent variable: ratio of US net imports from Mexico to US domestic production				
Post-NAFTA	.016**	.015**	.015	-.021
	(.0034)	(.0048)	(.016)	(.028)
Industry dummies	incl.	incl.	incl.	incl.
Air pollution intensity X post-NAFTA				
Particulate matter	-.00013	-.00018	.000053	.00034
	(.00029)	(.00030)	(.0013)	(.0018)
Carbon monoxide	.00021*	.00024**	.00044	.00050
	(.00011)	(.00011)	(.00048)	(.00067)
Sulphur dioxide	.000025	.000054	-.00013	-.000055
	(.00018)	(.00019)	(.00082)	(.0011)
Nitrogen oxide	-.00027	-.000052	-.00044	-.00037
	(.00036)	(.00040)	(.0016)	(.0024)
Volatile organic	-.00039	-.00031	-.00043	-.000011
compound	(.00029)	(.00031)	(.0013)	(.0019)
Particulate matter	.00018	.00012	.00021	-.00026
(<10 micron)	(.00031)	(.00032)	(.0014)	(.0019)
Toxic pollution intensity X post-NAFTA				
Toxic released	.00035	-.000086	-.00059	-.0014
to air	(.00038)	(.00044)	(.0017)	(.0025)
Toxic released	.000069	.000042	-.00026	-.0014
to water	(.00049)	(.00062)	(.0022)	(.0035)
Toxic released	-.0000056	.00023	.00048	.0014
as solids	(.00031)	(.00052)	(.00135)	(.0028)
Metal pollution intensity X post-NAFTA				
Metal released		.0041		-.54**
to air		(.044)		(.26)
Metal released		-.082		-.18
to water		(.096)		(.54)
Metal released		.00059		.011*
as solids		(.0011)		(.0063)

Table 5 (continued).

Water pollution intensity X post-NAFTA				
Biological oxygen		-.13		-.19
demand		(.27)		(1.57)
Total suspended		-.0025		.18
solids		(.028)		(.17)
Share of pollution abatement costs X				
post NAFTA	-.14	-.25*	.059	.44
	(.11)	(.14)	(.51)	(.86)
Injury rates X	-.00051**	-.00039	-.0012	.00040
post-NAFTA	(.00024)	(.00032)	(.0011)	(.0019)
Constant	incl.	incl.	incl.	incl.
No. of Obs.	2541	1473	2515	1467
Adj. R-squared	.11	.12	.35	.35

Notes: Pre-NAFTA years are 1991-1993. The coefficients of interest are those of the product of the post-NAFTA dummy and the pollution measures. If net imports grew faster in the more polluting industries than in the less polluting industries between the pre and post-NAFTA years, these coefficients would be positive.

** indicates significance at the .05 level. * indicates significance at the .10 level.

Table 6: OLS estimates of US net imports from Mexico pre and post NAFTA, allowing for variation in growth rates for industries that differ in their human and physical capital intensities.

	(1)	(2)	(3)	(4)
Post-NAFTA years	1994-6	1994-6	1997-9	1997-9
Pollution measures	Air & toxic	All	Air & toxic	All
Dependent variable: ratio of US net imports from Mexico to US domestic production				
Post-NAFTA	.022**	.015	.093**	.032
	(.0073)	(.021)	(.033)	(.12)
Industry dummies	incl.	incl.	incl.	incl.
Post-NAFTA X human cap. dummies	incl.	incl.	incl.	incl.
Post-NAFTA X physical cap. dummies	incl.	incl.	incl.	incl.
Air pollution intensity X post-NAFTA				
Particulate matter	-.00012	-.00020	-.00014	-.00026
	(.00029)	(.00031)	(.0013)	(.0018)
Carbon monoxide	.00023**	.00029**	.00062	.00080
	(.00011)	(.00012)	(.00049)	(.00069)
Sulphur dioxide	.000081	.000058	-.000020	-.00041
	(.00018)	(.00019)	(.00082)	(.0011)
Nitrogen oxide	-.00029	-.00015	-.00018	.00097
	(.00036)	(.00041)	(.0016)	(.0024)
Volatile organic	-.00031	-.00021	-.00028	.00083
compound	(.00030)	(.00033)	(.0014)	(.0019)
Particulate matter	.00014	.00020	.000086	-.00036
(<10 micron)	(.00032)	(.00033)	(.0014)	(.0019)
Toxic pollution intensity X post-NAFTA				
Toxic released	.00028	-.00023	-.00058	-.0032
to air	(.00038)	(.00046)	(.0017)	(.0026)
Toxic released	-.000074	-.000097	-.00082	-.0023
to water	(.00050)	(.00066)	(.0022)	(.0036)
Toxic released	.00013	.00043	.0012	.0031
as solids	(.00032)	(.00056)	(.0014)	(.0029)

Table 6 (continued).

<u>Metal pollution intensity X post-NAFTA</u>				
Metal released		.018		-.36
to air		(.047)		(.27)
Metal released		-.13		-.59
to water		(.099)		(.54)
Metal released		-.018		.0091
as solids		(.030)		(.0065)
<u>Water pollution intensity X post-NAFTA</u>				
Biological oxygen		.049		.054
demand		(.29)		(1.7)
Total suspended		-.018		.15
solids		(.030)		(.17)
<u>Share of pollution abatement costs X post-NAFTA</u>				
	-.12	-.25*	-.040	.20
	(.11)	(.15)	(.51)	(.87)
<u>Injury rates X post-NAFTA</u>				
	-.00034	-.00039	-.00092	-.00033
	(.00026)	(.00035)	(.0012)	.0020
Constant	incl.	incl.	incl.	incl
No. of Obs.	2541	1473	2515	1467
Adj. R-squared	.11	.13	.37	.37

Notes: Pre-NAFTA years are 1991-1993. Physical capital dummies indicate 9 different centiles of physical capital intensity. Human capital dummies indicate 9 different centiles of human capital intensity. The coefficients of interest are those of the product of the NAFTA dummy and the pollution measures. If net imports grew faster in the more polluting industries than in the less polluting industries between the pre and the post-NAFTA years, these coefficients would be positive.
** indicates significance at the .05 level. * indicates significance at the .10 level.

Table 7: No. of violations of the carbon monoxide air quality standard in Mexican border cities

Monitoring stations ▶	Ciudad Juarez-1	Ciudad Juarez-2	Ciudad Juarez-3	Ciudad Juarez-4	Tijuana 1	Tijuana 2	Tijuana 3	Tijuana 4	Mexicali 1	Mexicali 2	Mexicali 3	Mexicali 4	Rosarito
Year ▼						Pre-NAFTA years							
1990	2												
1991	0	9											
1992	1	0											
1993	0	3											
						Post-NAFTA years							
1994	0	0											
1995	0	2			0								
1996	0	0	8		0	3	0						0
1997	0	0	19		0	2	0		21	38	44	46	0
1998	0	2	22		0	1	0		27	49	64	86	0
1999		0	10	0	0	0	0	0		24	24	38	0
2000		0	0	0									

Notes: A violation is recorded when the carbon monoxide concentration exceeds the US National Air Quality Standard.
The standard used is 9 ppm for the 8 hour maximum CO concentration. Blank cells indicate that data is unavailable.

Table 8: No. of violations of the ozone air quality standard in Mexican border cities

Monitoring stations ▶	Ciudad Juarez-1	Ciudad Juarez-2	Ciudad Juarez-3	Ciudad Juarez-4	Tijuana 1	Tijuana 2	Tijuana 3	Tijuana 4	Mexicali 1	Mexicali 2	Mexicali 3	Mexicali 4	Rosarito
Year ▼						Pre-NAFTA years							
1990	0												
1991	4.9	4.5											
1992	2	4.8											
1993	1.2	0											
						Post-NAFTA years							
1994	8.6	9.4											
1995	0	2.3			0								
1996	2.2	1.2	2.4		0	0	0						0
1997	2.7	7	2.3		1	1	0		9.4	8.1	10.6	9	2
1998	4.9	0	1.1		0	0	0		10.2	4.4	2.3	10.8	0
1999		0	0	0	0	0	0	12		14	8.3	19.9	0
2000		3.6	3	4.3									

Notes: A violation is recorded when the ozone concentration exceeds the US National Air Quality Standard. As the no. of observations differ across stations, AIRS uses an interpolation technique based on the actual number of violations to calculate the estimated number of violations. The standard used is .125 ppm for the 1 hour maximum ozone concentration. Blank cells indicate that data is unavailable.

Table 9: No. of violations of the sulphur dioxide air quality standard in Mexican border cities

Monitoring stations ▶	Tijuana 1	Tijuana 2	Tijuana 3	Mexicali 1	Mexicali 2	Mexicali 3	Mexicali 4	Rosarito 1
Year ▼				Pre-NAFTA years				
1990								
1991								
1992								
1993								
				Post-NAFTA years				
1994								
1995	0							
1996	0	0	0					0
1997	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0
1999	0	0	0		0	0	0	0
2000								

Notes: A violation is recorded when the sulphur dioxide concentration exceeds the US National Air Quality Standard.