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The Effects of NAFTA on Energy and Environmental Efficiency in Mexico

Author: David I. Stern*

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* Department of Economics, Rensselaer Polytechnic Institute

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Commission for Environmental Cooperation
393, rue St-Jacques Ouest, Bureau 200
Montréal (Quebec) H2Y 1N9
Tel: (514) 350-4300 ; Fax: (514) 350-4314
E-mail: info@cec.org
http://www.cec.org

Introduction

Prior to Mexico's entry to NAFTA, predictions of the consequent impact on the environment in that country ranged from the dire to the very optimistic. This paper investigates NAFTA's outcomes in terms of energy use and the emission of atmospheric pollutants (carbon, sulfur, and NOx emissions). Up till now there have been a very small number of economic evaluations of the environmental impact of NAFTA after the fact, whereas there were very many discussions and predictions of its potential impacts. As Mexico was the smallest and least liberalized of the three economies, pre-NAFTA concerns focused on the impact of NAFTA on Mexico. Though I focus on the implications for Mexico, the three countries are treated equally in my empirical analysis.

Recent theory and empirical evidence on the relation between pollution and economic development suggests that there is a tendency for emissions per capita and per unit of GDP to converge over time across countries (Brock and Taylor, 2004; Stern, 2005). Convergence depends partly on the diffusion across countries of best practice technology in both emissions abatement and general economic productivity, which might be promoted by trade integration. Therefore, in addition to describing the pollution and energy use outcomes, I investigate whether entry into NAFTA led to a convergence in energy or emissions per capita and per unit of GDP and the state of emissions abating technology in Mexico, the United States and Canada. The state of technology is estimated using the method developed by Stern (2005) who estimated a production frontier model for sulfur emissions for sixteen OECD countries. This approach allows each country to have its own stochastic state of technology and to converge to or move away from the best practice frontier over time. The production frontier model is estimated using the Kalman filter.

The structure of the paper is as follows. Following this introduction, I discuss theory relevant to the effects of NAFTA on economic and environmental variables of interest, which sets the scene for the development of my model later in the paper. Following this, I discuss predictions of the impact of the NAFTA treaty on the environment in North America and review some of the evaluations to date of those impacts and the available information on Mexican environmental efficiency. These provide a background for evaluating the results of my analysis to be presented later. I then discuss the data and outline the research design, the model used for estimating emissions specific technological change, and the tests of convergence and structural breaks. Results and conclusions sections complete the paper.

Review of the Literature

Theory: Growth, Trade Liberalization, and the Environment

It is a commonplace concept that trade liberalization (including the formation of customs unions such as NAFTA) leads to scale, composition, and technique effects on emissions of pollutants (Grossman and Krueger, 1991; Copeland and Taylor, 2004; Gallagher, 2004). The technique effect can be further decomposed into the effects of changes in the mix of inputs and technological change; and technological change can be broken down into changes in general total factor productivity (TFP) and changes in emissions specific technology (Stern, 2004a). The scale effect is due to the increase in economic activity that results from trade liberalization and the composition effect due to trade specialization, holding aggregate output constant. Technique effects do not result so obviously from standard trade theory. There are two main possible channels. Open-ness to trade favors the adoption of better practice technologies developed in other parts of the world, whether through foreign direct investment (Grossman and Krueger, 1991) or not. It is usually assumed, and the empirical evidence shows, that this direct effect is environmentally beneficial (Copeland and Taylor, 2004). A second indirect effect occurs where open-ness to trade results in changes in government policy. This could be detrimental to the environment if a "race to the bottom" ensues (Dasgupta *et al*., 2002), or if trade regulators see environmental policy as an unfair trade barrier. The effect will be positive if, instead, there is a harmonization of standards towards better practice. Grossman and Krueger (1991) pointed out that growth in income might affect the demand for environmental quality resulting in policy change affecting scale, composition and technique. This is the environmental Kuznets curve (EKC) effect.

In the last two years, a new generation of emissions and growth models has emerged that emphasize technology and technological change rather than policy and preferences in determining the relationship between emissions and economic output and growth. These models are based on standard models of economic growth and the environment rather than the more specialized models of the earlier environmental Kuznets curve literature. The models explain the more nuanced view of the stylized facts uncovered by myself and other authors who have carried out decomposition and convergence analyses. In particular, the pure income effect on emissions seems to be monotonic 1 – technique effects and, particularly, technological change are the main cause of reduced emissions per capita.2 Furthermore, environmental innovations are adopted with a fairly short time lag in developing countries but countries differ in the extent to which they adopt the best practice technology. These differences cannot be explained by income per capita alone (Stern, 2005). Periods of fast economic growth tend to overwhelm the effect of improving technology in reducing emissions, which is why pollution rises in many fast growing middle-income countries. Finally, the trajectory of individual countries depends on factors such as endowments of natural resources and the consequent effects on industrial structure and input mix (Stern, 2002, 2005).

In a theoretical piece, Chimeli and Braden (2005) focus on differences in TFP across countries with the state of technology held constant in each country. Presumably, as in the growth theory of Parente and Prescott (2000), institutions determine the level of TFP in each country. Parente and Prescott (1999, 2000) theorize that international differences in TFP are in large part due to the barriers that governments impose that make it impossible or more expensive for producers to adopt the more productive technologies that are available in other countries. Lopez and Mitra (2000) develop a similar theory about the income-emissions relationship, where corruption leads to higher levels of pollution and a higher turning point for the EKC. Therefore, according to these theories, trade liberalization reduces the barriers to riches and should result in

1 Concentrations of pollution in urban areas do perhaps follow an inverted U shape relation with income because of the tendency to the dispersion of economic activity in the course of economic development through the processes of suburbanization and industrial decentralization (Stern, 2004a).

2 Technique effects as defined by Grossman and Krueger (1995), Copeland and Taylor (2004) etc. include both technological change and changes in input mix.

a convergence in TFP levels and emissions intensities across countries. In Chimeli and Braden's model, output, which can be used for consumption, capital accumulation, or environmental cleanup is a concave, increasing function of capital, while pollution is a convex, increasing function of capital. Social welfare depends on consumption and on environmental quality, which is damaged by pollution and improved by cleanup. Each country monotonically converges on a steady state with rising consumption and environmental quality along the transition path.3 But it turns out that environmental quality has a U shaped relation with TFP. Therefore, a cross-sectional EKC could be derived due to differing levels of TFP across countries even though each country's environmental quality improves monotonically towards the steady state. An implication is that "ignoring country-specific characteristics likely correlated with TFPs and income may produce biased and inconsistent estimates of the relationship between development and the environment" (Chimeli and Braden, 2005, 377), which is exactly what is found in numerous EKC studies which compare random and fixed effects estimates using the Hausman test (Stern and Common, 2001).

Brock and Taylor (2004) present and discuss the implications of four growth with pollution models which explore the potential effects of technological change and shifts in composition. In a clear sign of progress over the earlier theoretical EKC literature, their models do not just mimic purported observed features but generate refutable predictions. The "Green Solow Model" (GSM) is the standard Solow growth model with the addition of pre-abatement pollution emissions that are a linear function of output. Output can be used for consumption, abatement, or capital accumulation. A fixed fraction of capital and effective labor is used for abatement. Exogenous technological progress lowers the emissions-output coefficient over time and augments labor at independent rates.4 Unless the rate of emissions reducing technological change is greater than the growth rate of effective labor, the economy needs to increase the share of inputs devoted to abatement in order to maintain environmental quality. If emissions are falling along the balanced growth path then they will follow an EKC type path along a transitional growth path and the share of abatement in output will remain constant. This is because growth is faster at lower income levels than higher income levels in the Solow model and so overwhelms the abatement effort at lower income levels. This model matches some of the stylized facts.

The other models described in the paper: omit technological change, allow compositional change with pollution generated by energy use rather than output, and finally model both optimization and endogenous technological change (the Kindergarten Rule Model, KRM). The second and third models result in predictions – that the share of abatement is rising rapidly and that energy prices should rise rapidly over time – that are refutable. Neither of these models includes technological change and so this must be a major factor in explaining the historical evidence, which is exactly what is found by empirical studies.

3 This result depends on the specific calibration used.

4 A given fraction of the economy's inputs is assumed to clean up a given fraction of the pollution produced (with diminishing returns) rather than an absolute quantity of pollution. The model, assumes that increasingly clean techniques of production are adopted that produce smaller absolute quantities of pollution per unit output. If output is constant, abatement, therefore, cleans up fewer absolute tonnes of pollution over time, but the same fraction of the total pollution produced.

The KRM generates similar but more complex results than the GSM. Abatement converges to a constant share along the transition path, there is initially no pollution regulation, and pollution rises and falls in an EKC type pattern. However, each country will have a different income turning point and maximum emissions level. But countries converge to similar emission levels and intensities from different initial conditions and so “environmental catch-up” occurs. The authors also predict that long-lived pollutants should be addressed before short-lived ones. This only has partial if any support from the data I think. Another criticism of this model from an ecological economics perspective is that it assumes that complete abatement is possible. Nevertheless, I believe that the growth and environment literature is now moving in an interesting and useful direction.

As discussed below, opponents of NAFTA argued that as regulation was weaker in Mexico, Mexico would be a pollution haven and the introduction of NAFTA would result in a shift of polluting industry to Mexico. Taylor (2004) summarizes the state of knowledge on the pollution haven hypothesis. It is clear that differences in environmental regulation across countries generate a pollution haven effect: changes in environmental regulation will have a marginal effect on the location of polluting industries and trade in pollution intensive products. But it does not follow that reducing the barriers to trade will result in a shift in trade and investment patterns such that polluting activity shifts to the less regulated regimes (the pollution haven hypothesis). This is because a host of other factors such as endowments and laws and regulations in other policy areas also determine trade and the location of investment. The empirical evidence is insufficient to either reject or accept this hypothesis in general. Taylor also concludes that “the relationship between trade, technology and the environment is not well understood … [because] too little [emphasis has been placed] on how openness to world markets affects knowledge accumulation and technology choice. This is surprising, because it is widely believed that technology transfer to poor developing countries will help them limit their pollution regardless of the stringency of their pollution policy or their income levels. If the diffusion of clean technologies is accelerating as a result of globalization, this indirect impact of trade may well become the most important for environments in the developing world.” (25) Therefore, neither theory nor experience from elsewhere can predict, *a priori*, what the effect of NAFTA is likely to be on the environment in Mexico, especially if the diffusion of technology is an important result of opening to trade.

Testing for Convergence, Structural Breaks, and Lags in Emissions:

A small number of studies have tested for convergence of pollution levels and intensities across countries and for structural breaks that may reflect the impact of policies. Structural breaks are relevant, as NAFTA might introduce a structural break in the series. Lanne and Liski (2004) and Lee and List (2004) look for structural breaks in the evolution of pollution time series that reflect either the effects of policy, the oil price shocks, or other macroeconomic developments. Lee and List (2004) test the effect of the 1970 U.S. Clean Air Act on NOx emissions. The time series from 1900-1994 has a unit root, which disappears when a structural break in 1970 is allowed for. Intervention analysis shows that the policy had gradual but permanent effects, while forecasting emissions for the post-1970 period using an ARIMA model estimated only on pre-1970 data shows that the policy reduced emissions by 27-48%. Instead of assuming a known structural break, Lanne and Liski (2004) use the Vogelsang and Perron (1998) test to find structural breaks in long-term carbon dioxide per-capita emissions series for a number of developed economies since 1870. Generally, they find structural breaks in the late 19th or early 20th century rather than in the period of the OPEC oil price shocks. For a few countries, though, a unit root process with no structural breaks fits the data best.5 The ensemble of series shows clear convergence over time. Strazicich and List (2003) use cointegration tests as well as more traditional convergence tests to find convergence of CO2 per capita in 21 industrialized countries between 1960 and 1997. The carbon emissions from fossil fuels / GDP intensity has also converged in a group of 28 developed and developing countries between 1870 and 1992 (Lindmark, 2004). This indicator exhibits an inverted U-Shape path over time, but the later the peak occurs in each country the lower its level.

Alvarez *et al*. (2005) expand the convergence study to more indicators (CO_2, NO_2, and SO_2) but a much shorter period (1990-2000). There is indication of □-convergence 6 for the former two pollutants in the entire EU zone and for the latter in the core EU-10. The residuals from these regression analyses are used to rank the relative “cleanliness” of the different countries in similar fashion to Stern (2005) and with similar results, though here Britain is included in the clean group. Faster growth also leads to increased pollution, in line with the emerging theory described above, while higher initial pollution leads to a faster reduction in pollution.

Hilton (in press) investigates the lag in the diffusion of emissions abatement technology from the developed to the developing world using the example of the phase-out of leaded gasoline. He finds that the typical developing country lags the typical developed country in implementing this policy but adopts the policy at a much lower income level. There is a statistically significant relationship between the income level at the time the lead phase-out was introduced and the year in which it was introduced. India, Côte d’Ivoire, Kenya, and Myanmar are the poorest countries in the sample to have commenced lead abatement at income levels of less than $1000 in the late 1980s. Japan was actually the first country to cut lead for its own sake, starting in 1970, the same year that the US decided to introduce catalytic converters, that can only operate with unleaded fuel, in order to remove other pollutants. As this technology eventually became ubiquitous in cars manufactured in developed countries by the 1990s introduction of unleaded gasoline became inevitable in most developing countries too.

Predictions of the Effects of NAFTA

As part of a larger literature that discussed the potential environmental impact of NAFTA, Grossman and Krueger (1991) and Kaufmann *et al*. (1993) wrote predictions of what would happen to emissions of pollutants and the quality of the environment under NAFTA. Daly

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5 No existing studies tests a unit root process without structural breaks against a unit root process with a structural break in the drift component. The latter is one of the alternative models considered in the current paper.

6 β-convergence occurs when the rate of change of a variable across countries is correlated with the initial values of the variable in those countries.

(1993) included the potential effects of NAFTA in a general article attacking free trade. Reinert and Roland-Holst (2001) predict the impacts of NAFTA on industrial pollution using an applied general equilibrium model. Grossman and Krueger (1991) concluded their influential paper:

> "while [environmental advocacy groups] raise a number of valid concerns, our findings suggest that some potential benefits, especially for Mexico, may have been overlooked…. Mexico is at the critical juncture in its development process where further growth should generate increased political pressures for environmental protection and perhaps a change in private consumption behavior… Trade liberalization may well increase Mexican specialization in sectors that cause less than average amounts of environmental damage… a reduction in pollution may well be a side-benefit of increased Mexican specialization and trade." (35-36).

By contrast, Kaufmann *et al*. (1993) took a much more pessimistic view that has been more accurate but far less influential in the economics community7. While Grossman and Krueger (1991) focused on finding potential environmental benefits for NAFTA, Kaufmann *et al*. "focus on … the potential for NAFTA to reduce social welfare by degrading the environment" (xx). Mechanisms they cited include: the elimination of existing environmental regulation and using environmental externalities as a source of comparative advantage. The potential for the exploitation of genuine comparative advantages in the quality of resource stocks to mitigate the environmental impacts of their use was seen to be offset by NAFTA provisions allowing for subsidies to be retained in the extractive sector. Growth in scale of the economy was seen as exacerbating existing externalities, which would offset the possibly positive effects of the exploitation of economies of scale. Kaufmann *et al*. (1993) argued that it was impossible to know, *a priori*, whether NAFTA would have a positive or negative effect on the environment. Daly's (1993) view by contrast was very clear-cut. He saw the perils of freer trade as being so severe that he advocated more self-sufficiency and less trade. He predicted that Mexican production of agricultural staples would decline, being replaced by production of specialized crops for export such as vegetables and flowers. Capital would flow to Mexico to exploit both low wages and environmental regulations resulting in increased pollution.

Reinert and Roland-Holst (2001) use an applied general equilibrium model calibrated to a 26 sector 1991 social accounting matrix for the three NAFTA countries linked to satellite accounts for fourteen pollutants. The simulation removes tariffs among the partners and observes the resulting changes in pollution after the system moves to a new static equilibrium. Most types of pollution increase in the three countries but there are large differences in the changes in pollution across the different industries in each country. The greatest impacts are predicted in the US and Canada and particularly in the base metals industry, though there are important increases in pollution from the Mexican petroleum sector. Regarding the pollutants examined in the current study, much greater increases in sulfur dioxide than NOx were predicted in each country

7 Their paper has received three citations in the *ISI Citation Index* compared to hundreds of citations for the various versions of Grossman and Krueger's paper.

with increases in the US and Mexico about twice as large as in Canada. It is not easy though to compare these results to those in the current study as the Reinert and Roland-Holst model is a static equilibrium with no technological change and only covers industrial pollution and not electricity generation, transportation or other important polluting sectors.

Evaluations of the Environmental Impacts of NAFTA

Eleven years after the introduction of NAFTA there are relatively few general assessments of the impact of NAFTA after the fact from an economic perspective, which makes the three Symposia organized by the Commission for Environmental Cooperation of great value. Schatan (2002) reports on Mexico's manufacturing exports and the environment in the first five years of NAFTA. Cole (2003) investigates the effects from the perspective of US production, consumption, and trade, while Gallagher (2004) examines the impacts of NAFTA from the Mexican perspective.

Schatan (2002) situates NAFTA in an ongoing process of trade liberalization in Mexico that began in 1987. Mexico saw very rapid export growth after 1994 8 but had already seen a greater change in the mix of its exports (from primary exports to manufactured and high tech exports) in the two decades prior to NAFTA than any country in the Americas. The greatest growth in exports relative to imports occurred in relatively low pollution sectors. The largest amounts of foreign direct investment flowed into machinery, automobiles, food, and beverage production in 1994-8. The same is true when we look at exports to the US alone. Schatan finds that manufactured exports increased 171% between 1992/3 and 1997/8, but, if we assume that there were no technique effects, pollution emissions from manufacturing exports only increased by 87% due to the composition effect. It is hard to imagine that the technique effect could be big enough to offset the remaining scale effect. While the manufacturing sector itself and manufactured exports in particular are most directly and dynamically affected by NAFTA, direct emissions from manufacturing are only part of the picture, induced increases in emissions from transportation, electricity generation, oil refining etc. need also to be considered.

Though Gallagher (2004) also focuses on the manufacturing sector, his is the first comprehensive assessment of the Mexico-wide impact of NAFTA on the environment. He finds that the growth of the Mexican economy during this period led to increased environmental degradation, but that the relative role of heavy industry declined in Mexico – there was no net pollution haven effect. Both sulfur and carbon dioxide emissions increased with increasing income, though growth in GDP was very moderate.

Cole (2003) concludes that while US imports from Mexico have increased more than US exports to Mexico, there is no evidence that this is resulting in "environmental displacement" from the US to Mexico. In fact, while the US does import more embodied pollution than it exports to all countries, its balance of trade in embodied pollution is reversed in the case of Mexico. Since the

8 Of course, there was a major devaluation of the Peso in late 1994, which also would have encouraged export growth.

introduction of NAFTA this pattern has become more and more pronounced.

The reality of NAFTA seems to be somewhere between the extremes painted by Grossman and Krueger and Daly and closest to the ambivalent picture outlined by Kaufmann *et al*.

Mexican Environmental Efficiency

Aguayo and Gallagher (2005) investigate changes in energy intensity in Mexico, which they find increased until 1988, after which it declined. This contrasts with results for most developed economies and China where intensity has been falling in recent decades and for some developed economies where energy intensity has been falling for a century or two including Sweden and Spain (Kander and Rubio, 2004) and the USA (Stern, 2004b).[9] However, Mexico's energy intensity in 2000 was less than that of the US and several European countries and comparable to Germany and Japan. Canada's energy intensity was higher than that of any other developed country.[10] As in other countries, the decline in energy intensity from 1988 to 1998 in Mexico was largely due to declining intensity in industry. Within the industrial sector, declining energy intensity in energy intensive heavy industries offset increasing energy intensity in lighter industries. There has also been a shift away from the most energy intensive industries and the embodied energy in Mexican imports has increased. But there also appears to be genuine technological progress within some industry sectors.

Interestingly, the decline in Mexican energy intensity starts just as liberalization began. China's energy intensity also only began to decline from 1979 with the opening of the economy. This suggests that NAFTA will continue to have beneficial effects on Mexican energy intensity.

Stern (2002) finds that, in a group of 64 countries between 1973 and 1990, Mexico is fairly inefficient in the emission of sulfur. It had roughly twice the level of emissions of the US when the level of income and the input-output structure of the economy were taken into account. Canada's efficiency level was midway between that of the US and Mexico. Relative efficiency was fixed in that study, while in the current study, the relative efficiency of countries can change over time.

Methodology

Data

The sources of the data are described in the Data Appendix. I constructed continuous time series for the three NAFTA countries for 1971-2003 for sulfur, NOx, and carbon emissions, energy use by fuel, GDP in purchasing power parity Dollars, population, shares of industries in value added, oil refining (as measured by crude oil consumption), and the smelting of copper,

9 This is if traditional fuels and energy carriers are included. When only fossil fuels and other modern energy carriers are included the time profile of emissions intensity tends to be an inverted U.

10 From *IEA* and *World Bank* data collected for Stern (2005).

lead, nickel, and zinc. Complete series are available for all of the explanatory variables and energy use as well as sulfur emissions. Complete CO2 series were also obtained with the exception of 2003 emissions in Mexico. For NOx, availability is as follows: Canada, 1980-2002; Mexico, 1985-2003; and USA, 1971-2003. All the underlying sources consist of annual time series data. I did not interpolate or extrapolate any data points. However, in a few cases, described in the Appendix, I have adjusted different sources so that they splice together smoothly. Figures 1 to 4 present each of the four series for the three countries. In Mexico total energy use and all three emissions series increase over time, though the two criteria pollutants may be beginning to decline in recent years. Energy use and carbon emissions rise in the US and Canada while the criteria pollutants and stable or falling (Figures 1 through 4).

Research Design

The method has three stages – computation of the various indicators of environmental efficiency, convergence analysis using the computed trends, and tests for structural breaks in the series. As the length of available time series for different countries and variables differ, the convergence tests are limited in each case by the country with the shortest emissions time series. As the structural break tests are applied to one country at a time, the full time series for each emission and country can be examined.

My methodology does not allow us to specifically identify which changes are due to entry to NAFTA and which are not.11 On the other hand, it does allow us to assess both the overall change in environmental quality that has occurred and the changes in the different components of the technique effect. This allows us to determine whether environmental quality and environmental efficiency improved at a faster rate post-NAFTA in Mexico and whether Mexico is converging with the US and Canada to a greater degree post-NAFTA than before. I compute each of the following measures and test for convergence among them pre- and post-NAFTA:

Changes in environmental quality – emissions per capita (assuming population change is not induced by trade liberalization) - encompasses scale, composition, and technique effects.

Changes in emissions intensity – emissions per unit output – expresses the effect of composition and technique effects (assuming constant returns to scale).

11 Because this study, like the environmental Kuznets curve literature, is very much a macro-economic study it is not possible to relate these effects directly to the different linkages to the environment discussed in the CEC Analytical Framework (CEC, 1999). The various effects listed under "Production Management and Technology" (pp13-14) can be potentially identified but the underlying factors such as the relative roles of government policy (pp16-17) or private sector initiatives (p4) cannot be differentiated. In particular we can identify the effects of input mix (item 1, p14), relative production efficiency in different countries (item 2), a composite of physical technology and management (items 3 and 4), output mix (item 5), and most importantly scale which appears to be amalgamated with efficiency in the framework.

Changes in environmental efficiency – which hold constant the structure of inputs and outputs in each economy – express just technological change effects.

For pollutants such as sulfur and NOx where there are viable abatement technologies the technological change effect can be further decomposed into total factor productivity between conventional inputs and outputs and the state of emissions specific technology. For a given level of output, output mix, and input mix, the level of inputs required is a function of TFP – the output per unit input that can be achieved. But given these particular quantities of inputs, emissions will differ according to the abatement technology and amount of abatement employed. The consequent level of emissions per unit input is the emissions specific state of technology. Due to a lack of sufficient data for NOx a frontier model was only estimated for sulfur. As described below, a similar model was also estimated for energy efficiency.

Frontier Model for Sulfur

The frontier model for sulfur is, as developed in Stern (2005), a logarithmic or Cobb-Douglas production frontier model with stochastic technological change. The Cobb Douglas form is the simplest function with desirable properties for a production frontier.12 The model explains the level of emissions as a function of the inputs and outputs and the state of technology:

$$\ln E_{it} = \ln A_{it} + \sum_{k=1}^{4} \gamma_k \ln y_{kit} + \gamma_x \ln\left(\sum_{j=1}^{n} \beta_j x_{jit} \right) + u_{it} \quad (1)$$

This equation is estimated as a group of seemingly unrelated time series equations, one for each country. The variables and parameters are defined as follows:

E_{it} is emissions of the pollutant in question in country i and year t.

A_{it} is the state of technology in emissions abatement. As described below, it is modeled as a stochastically trending state variable using the Kalman filter.

y_{kit} are the four output variables: agricultural, non-manufacturing industry, manufacturing, and services value added.

γ_k are regression type parameters that sum to zero. Imposition of zero degree homogeneity means that increasing all outputs proportionally has no effect on emissions. An increase in output holding input constant is an increase in TFP. I assume that this increase in knowledge does not itself change the level of pollution if the level of inputs is held constant. Changing the mix of outputs does, however, affect the level of emissions.

γ_x is the returns to scale in inputs parameter which allows pre-abatement emissions to rise more slowly than the quantity of inputs, or vice versa.

12 A production frontier is a multi-output production function.

x_{jit} are the inputs. For the sulfur model these are: consumption of coal, oil, natural gas, hydropower, nuclear power, and biomass energy, primary smelting of copper, lead, zinc, and nickel and oil refining (primary supply of crude oil).

β_j are regression type parameters which sum to unity. Because some inputs, such as nuclear power, oil refining, or zinc smelting are zero in some countries in some years, a function that can accommodate zero values for some inputs is needed to introduce the inputs into the model. As in Stern (2002), I use a linear function of the inputs, which is homogenous of degree one and makes the (questionable) assumption that the inputs are infinitely substitutable for each other. As emissions are homogenous in the input aggregate, $\sum_{j=1}^{n} \beta_j x_{jit}$, the model is not identifiable 13 unless a restriction is placed on the parameters, β_j, or on the state of technology. This is the rationale behind the arbitrary restriction that these parameters sum to unity.

u_{it} is a random error term representing measurement error or short-run optimization error which may be correlated across countries so that the their covariance matrix is unrestricted. I also estimated models with a diagonal error covariance matrix and found that this restriction can be easily rejected (The likelihood ratio statistic is 8.91 which is chi-square distributed with three degrees of freedom and, therefore, $p=0.03$).

Model for Energy Efficiency

The state of technology in carbon emissions abatement is expected to be constant as there are no current technologies for sequestering carbon apart from growing trees, which is not accounted for in the computation of carbon emissions data. Furthermore, emissions of carbon should not depend on which sector of the economy is using the fuel. Therefore, changes in the carbon emitted per unit of energy are purely input mix effects and environmental efficiency reduces to simply a question of energy efficiency. An alternative approach (e.g. Fernandez *et al.*, 2002; Lansink and Silva, 2003) would treat any deviation from the carbon-minimizing vector of inputs as an inefficiency.

To estimate the adjusted indicator of energy efficiency, we estimate the output distance function (Shephard, 1970):

$$\sum_{k=1}^{4} \gamma_k \ln y_{kit} + \gamma_x \ln\left(\sum_{j=1} \beta_j x_{jit} \right) = A_{it} + v_{it} \quad (2)$$

13 A non-identifiable econometric model is one which cannot be estimated as more than one set of parameter estimates are compatible with the same error terms. Identification ensures that there is a unique vector of regression coefficients.

where v_{it} is a random error term. Homogeneity of degree one is imposed on the output coefficients and the input coefficients, □j, sum to unity. The returns to scale parameter, γ_x, is expected to be negative. The vector x consists of the energy inputs only. The model is estimated with a dependent variable of zero and, therefore, the traditional goodness of fit measure is inapplicable.

The Kalman Filter

The Kalman filter is an algorithm that originated in control engineering for estimating unobserved time-varying state variables and has numerous applications in modern time series econometrics. The first step in applying the Kalman filter to an estimation problem is to reformulate the model in question in terms of a state space model. A state-space model includes both a system of regression equations as in (1), known as the measurement equations, and a second system of equations, known as the transition equations, which model the evolution of the unobserved state variables. The transition equations are very similar in form to regression equations for autoregressive time series models, but instead of regressing observed variables on their lagged values, the unobserved variables are modeled as a function of their past values, possibly other variables, and random errors.

I model the technology trends as integrated random walks with noise,14 which is the most general of the models typically used to represent the state of technology (Harvey and Marshall, 1991). In this case the transition equations are:

$$A_{t+1} = A_t + a_t + H_A \eta_t$$
$$a_{t+1} = a_t + H_a \eta_t \qquad (3)$$

where η_t is a 6-vector of independent random error processes with a variance of one and mean zero. A_t and a_t are 3-vector of stochastic trends – one trend A_{it} and one slope component a_{it} for each of the three NAFTA countries. The matrices $H_A = [h_A, h_a]$ and $H_a = [0, h_a]$ are 3X6 matrices that model the structure of the correlation of the random shocks across countries. The lower case matrices h_A and h_a are lower triangular matrices. If these matrices are diagonal then technology evolves completely independently in every country. Convergence of technology across countries requires that the state variables representing the state of technology in each country cointegrate with each other.15 For this to occur, none of the random shock variables can

14 This is a second order integrated process, designated I(2), and is also known as the local linear trend model.
15 Cointegration occurs when variables that contain random walk components or stochastic trends share these components so that some weighted sum of the variables does not contain a random walk. If this does not occur then a regression using these variables will end up with a random walk in the residual term which violates the classical regression assumptions and invalidates any inference based on the the regression results. If a group of variables cointegrate then, despite each following a random walk, the group will tend to move together and following shocks

be completely independent of all the others, which can be tested by examining the covariance matrix of the shocks. If any of the rows of h_a are null, then the relevant trend A_{it} is I(1) (first order integrated) with a constant drift. If the relevant row of h_A is also null then the trend is linear. The slope components, a, are, therefore, potentially time varying. I also estimated a model without the slope components – this restriction can be rejected at a very high level of significance.

The Kalman filter estimates time series for each of the state variables given the values of the covariance matrices of the shocks in the measurement and transition equations and the parameters γ and β in the frontier model, which are collectively known as hyperparameters. The filter is also used to compute the prediction error decomposition of the likelihood function in parallel with the state vector. This likelihood function in maximized using the BFGS nonlinear optimization algorithm to find the maximum likelihood values of the hyperparameters. Given maximum likelihood estimates of the hyperparameters, the Kalman filter produces maximum likelihood estimates of the state variables using only data for previous periods. Given these estimates, a smoother algorithm is used to calculate values for the unobserved state variables utilizing the entire dataset. The initial state can be estimated using the diffuse Kalman filter algorithm (De Jong, 1991a, 1991b).

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which push the variables apart, they will tend to converge with each other again.

Structural Break Tests

The hypothesis we are testing is that the slope of the trend in each of the variables under consideration changed post-NAFTA. Tests for the presence of a structural break and a unit root are intimately connected with each other. Perron (1989) pointed out that unit root tests that did not take into account the presence of a structural break were biased towards finding a unit root in the series when in fact the data generating process was trend stationary with a one time jump in the series at the structural break. A more general test that also allows for a change in the slope of the trend was developed by Park and Sung (1994):

$$\Delta y_t = \alpha + \beta t + \delta_1 D_t + \delta_2 D_t t + (\rho - 1) y^*_{t-1} + \sum_{i=1}^{n/3} \Delta y_{t-i} + \varepsilon_t \quad (4)$$

where y_t is the logarithm of the series being tested and for $t > m$, $y^*_{t-1} = \frac{n}{n-m} y_{t-1}$; while for $t \le m$, $y^*_{t-1} = \frac{n}{m} y_{t-1}$ and the first m of the n observations occur before the structural break. ε_t is a white noise error process, D_t is a dummy variable equal to zero before the structural change and one afterwards and t is a linear time trend. The test for a unit root is the t-test on $\rho - 1$ with critical values tabulated in Park and Sung (1994).

If the series is found to be stationary around the trend then the appropriate model to estimate is:

$$y_t = \alpha + \beta t + \delta_2 D_t t + \upsilon_t \quad (5)$$

The test for a structural break in the slope is the standard t-test on δ_2. If the series has a stochastic trend, the appropriate model is:

$$\Delta y_t = \alpha + \delta_1 D_t + \upsilon_t \quad (6)$$

The test for a change in the drift term is the standard t-test on δ_1.

The trends from the frontier model have potentially time varying slopes, *a*, as modeled in equations (3). We can directly examine these slopes to determine if there is a change in the slope post-NAFTA. The Kalman filter provides an estimate of the standard error of the state variables. A significant change in trend occurs if the post 1994 slope is outside the pre-1994 confidence interval.

Convergence Tests

I adapt the methods developed by Stern (2005) to test for convergence across the NAFTA countries and the effect of NAFTA on the convergence process. I test for convergence in three ways: so-called β– and σ– convergence (Quah, 1996) and a cointegration based test of convergence. 16

In the current context, β– convergence tests whether there is a negative correlation between the initial levels of efficiency and the growth rate of efficiency. If there is such a correlation, efficiency rose faster in initially less efficient countries and so those countries converged to the best practice frontier (Quah, 1996). Usually, this test is computed using the average rate of growth over the sample period and the initial level of the indicator, but here there would only be three observations with which to compute the correlation or regression. Instead, I estimate the following regression:

$$\Delta y_{it} = \alpha + \beta y_{i0} + \delta_1 D_t + \delta_2 D_t y_{i0} + \varepsilon_{it} \qquad (7)$$

where the variables are in logarithms and we can test whether is significantly different from zero using a standard t-test computing the standard error using a method robust to serial correlation of unknown form (The RATS ROBUSTERRORS procedure). The initial value, y_{i0}, is the first observation available.17 The mean of the initial value across countries is deducted from these initial values so that α is the unconditional growth rate of the variable in question. The dummy variable D is used to test the effect of NAFTA.

σ-convergence looks at the cross-sectional variance of efficiency over time. Decreasing variance over time implies convergence. Due to the small sample, I do not formally calculate the variance.

Both these tests are applied to the computed or extracted trends. The effect of NAFTA can be discerned by comparing the results in the pre-NAFTA period to those in the full sample. The post NAFTA period is probably too short to be examined on a stand-alone basis.

Cointegration implies that the state of technology in each country shares common stochastic trends with the states in the other countries. In the absence of exogenous shocks the countries' technologies will tend towards a long-run equilibrium with each other and converge. Without cointegration, convergence is impossible. But this does not necessarily mean that convergence will occur within the period under consideration. Convergence will depend on the standard deviation of the shocks and the rate of adjustment to long-run equilibrium. Hence, the usefulness of the β– and σ– convergence tests. An important caution in interpreting these tests is that two or more stochastic trends can cointegrate to a stationary variable with non-zero mean. For example y and x in the following model:

16 See Durlauf and Quah (1998) and Carlino and Mills (1993) for references to the early literature on cointegration as a convergence test.
17 Mostly 1971 but as late as 1985 in the case of NOx emissions in Mexico.

$$y_t = \beta_0 + \beta_1 x_t + w_t \tag{8}$$

cointegrate if w_t is stationary, but unless $\beta_0 = 0$ and $\beta_1 = 1$ the two series are not equal in the long-run. This is termed "conditional convergence" in the growth literature (Strazicich and List, 2003). Stegman (2005) argues that conditional convergence allows a linear time trend to be present as well.

The cointegration test can be applied to both the computed trends and integrated into the Kalman filter model. To apply cointegration testing to the computed or extracted trends, I use Strazicich and List's (2003) approach. First the logarithm of the cross-country mean in each year is computed and subtracted from the logs of the trends in each country so that they are now in terms of deviations from the logarithm of the international mean. Then the Im, Pesaran, and Shin (2003) unit root test (IPS test) is applied to test if the panel of resulting series contains random walks or stochastic trends, also known as unit root processes. If we can reject the null hypothesis of a unit root, then the deviations are stationary and the series cointegrate. It seems that we could test the effects of NAFTA by splitting the panel into a group of NAFTA and non-NAFTA observations and applying the test to the subsets. However, there are only 24 post-NAFTA observations for the NAFTA partners so the power of this test may not be high.

The cointegration test that is integrated into the Kalman filter procedure is based on testing the significance of the coefficients in the matrices h_A and h_a in (5). For cointegration of the trends, each of these matrices must be of reduced rank. This condition is necessary but not sufficient. For example, in the following structure for h_A:

$$h_A = \begin{bmatrix} h_{A11} & 0 & 0 \\ 0 & h_{A22} & 0 \\ 0 & h_{A32} & 0 \end{bmatrix} \tag{9}$$

the second and third trends will cointegrate as they share a common shock, but the first trend is completely independent of the second and third trends. So attention needs to be paid to the significance of each coefficient in H.

For a formal test of the effect of NAFTA, we could use dummy variables to allow H to change value after 1994. This tests whether the state of emissions specific technology in Mexico became more correlated with fluctuations in the state of technology in the other two North American countries after entry to NAFTA. In other words, did emissions specific technology converge within NAFTA? Or perhaps convergence was already taking place, if there is cointegration in the pre-NAFTA period?

Results

Exploratory Analysis

Figures 5 to 12 present per capita and GDP intensity series for each of the four environmental indicators – energy use, carbon emissions, sulfur emissions, and NOx - for the three countries. Table 3 gives the mean growth rates of the eight variables across the three countries in the column headed α. For all four indicators a common pattern emerges. Mexico has far lower levels of the variable in per capita terms and similar levels to the US and Canada in GDP intensity terms. In terms of intensity, Canada is in recent years the "dirtiest country", in per capita terms either Canada or the US is dirtiest.

The level and pattern of per capita energy use and intensity over time is very similar in both the US and Canada. In Mexico, per capita energy use increases till the early 1980s and then flattens out at a level far below that of its neighbors to the North. Energy intensity in the three countries appears to converge over time and some of the same short-term movements are visible in all three countries. Not surprisingly, the patterns in the carbon series are quite similar. In recent years, energy and carbon intensity decline across the continent.

Convergence is more pronounced in the sulfur series. Per capita emissions declined in all three countries in recent years. Mexican sulfur intensity declines from the late 1980s after rising till the early 80s and ends up essentially identical with the level in Canada in the current decade. Differences in NOx emissions per capita are most pronounced with Mexico remaining the "cleanest" country over the period. However, per capita emissions and intensity rise in Mexico till the end of the 1990s and only show a sign of decline in the final year.

But these statistics hide important scale effects. Population rises 46% in Canada from 1971 to 2003, 95% in Mexico, and 40% in the United States. As noted above, energy use and carbon emissions have, therefore, risen in all three countries over the period. Sulfur and NOx emissions have risen in Mexico and NOx has only declined moderately in the two developed countries (Figures 1 through 4).

There is no visually obvious structural break in the data in 1994. In the energy and carbon data there is some sign of an increase in the per capita measure in Canada and a decrease in intensity in Mexico accelerating after that date.

In summary, these data conform to the recent literature on the emissions income relation discussed above. Per capita levels of local pollution emissions and energy and carbon intensity are declining with a lagged but eventual response in the developing country while in fact even in GDP intensity terms the developing country is cleaner than the developed world countries.

Unit Root and Structural Break Tests for per Capita and Intensity Indicators

Table 1 presents the Park and Sung (1994) unit root tests that take into account a possible structural break in 1994 and a time trend. The critical value at the 5% level is -4.153 and at the 10% level -3.869. Therefore, clearly we cannot reject the null hypothesis that all the series have a unit root. Therefore, I use equation (6) to test for a structural break.

Table 2 presents the t-statistics for the regression coefficients of the dummy variable in those regressions, which have standard t-distributions. The majority of the statistics are not significant at traditional significance levels. For the US the two NOx variables and the two sulfur variables all see increases in the rate of decline with significance levels of 5-10%. Canada sees a significant increase in the rate of decline only in the case of the NOx intensity and a significant increase in the growth rate of per capita carbon emissions. Mexico has no dummy coefficients that are significantly different to zero at greater than 10% levels but all but one of its t-statistics are negative. Therefore, while there is no strong evidence from this data that NAFTA improved environmental outcomes in Mexico, there certainly is no evidence that it made things worse and it may be associated with improvement in the US.

Convergence Tests for per Capita and Intensity Indicators

Table 3 presents the results of the β-convergence test. With the exception of energy and carbon per capita, all the series are declining, though the mean growth rate of NOx per capita is not significantly negative. The initial value of the variable in question has a significantly negative coefficient in every case and in all but one case the coefficient is highly significant. This is strong evidence for convergence across the three countries. The apparent effect of NAFTA varies though. On the whole, the coefficient of the NAFTA dummy is negative but only significantly different from zero at the 5% level for Energy/GDP and NOx/GDP and at a lesser degree of significance for energy per capita. This implies that the rate of increase in efficiency accelerated post-NAFTA though mostly not in a very significant way. The interaction variable between the dummy and the initial value of the variable has a positive coefficient for the first six variables, but an insignificantly negative coefficient for the two NOx variables. This implies that for the first six variables the effect of the initial level of the variable is significantly reduced or eliminated in the post NAFTA period, which implies that β-convergence comes to an end after NAFTA.

However, as we can see from the figures, the reason for this is that the trend in the variables becomes flat or negative in Mexico in the post-NAFTA period. So the ending of β-convergence may be environmentally beneficial!

By looking at Figures 5 through 12, σ-convergence is apparent in the energy and carbon intensity series and both the emissions per capita and intensity series for both sulfur and nitrogen. As generally the trend in Mexico is rising in the first part of the sample period this σ-convergence would also be apparent using a logarithmic scale.

Table 4 presents the results of the Strazicich and List (2003) tests for cointegration using the IPS unit root test on transformed data. Due to the small number of observations in the post NAFTA data the results for the sub-periods are based on the simple Dickey Fuller test while I also present results for the full period using the augmented Dickey-Fuller regression with three lagged first differences. Based on the results in Im et al. (2003) for five and more countries, I estimate that the critical values for three countries with 30 time series observations are -2.25 and -2.10 at the 5% level and 10% significance levels respectively. In the full sample clearly there is cointegration for the two different indicators for energy, carbon, and sulfur, but not for NOx, though the sample size is smaller for this pollutant. Critical values are a little larger in absolute value for the two sub-periods. These statistics are generally smaller in absolute value than the full period statistics. A couple of the intensity series appear to cointegrate in the post-NAFTA period. None cointegrate in the pre-NAFTA period.

I conclude from this section that there is strong evidence for convergence across the three countries though the strength of this evidence varies across the different indicators. The rate of improvement in the environmental indicators may have picked up in the post-NAFTA period.

Results for the Frontier Models

Energy

Tables 5 to 7 present the results of the estimation of the frontier models for energy and sulfur. Table 5 shows that the energy model passes the tests for whiteness of the residuals at reasonable significance levels. A likelihood ratio test allows the rejection of the restriction that the observation errors are independent across the three countries at the 2% level.

The energy input coefficients shown in Table 6 should be reflective of energy quality – a joule of electricity used has a different effect on economic output than a joule of coal. Usually electricity is found to be the highest quality (most productive) energy vector and biomass and coal to be the lowest quality. But here biomass has the highest quality factor and nuclear a negative coefficient. Clearly, these estimates are problematical. Possibly the coefficients are likely biased due to the small sample of countries with differing economic structures, which can induce spurious correlations. The returns to scale is 0.78, which here indicates decreasing returns to scale. The output coefficients should reflect the average shares of the four outputs in GDP and this seems to be approximately the case – only the coefficient for non-manufacturing industry is too small.

Table 7 shows that the technology trends are I(1) (simple random walks) with constant drift terms. There are two common stochastic shock shared by the technology trends in the three countries and, therefore, we find that the trends cointegrate. However the second shock has opposing impacts on the Mexican and US trends and Mexico only insignificantly participates in the first shock. The negative drift terms (Table 5 and Figure 13) show that the state of technology in energy efficiency is improving in all three countries, so that in absolute terms there is convergence across the NAFTA region, but as the trends are more negative in Canada and the US convergence does not occur in logarithmic or percentage terms. As mentioned above, restricting these drift terms to zero can be strongly rejected, which is again confirmed by the highly significant t-statistics on the individual slope components presented here in Table 5.

Figure 13 presents the extracted technology trends for the energy model. The scale is arbitrary. According to these results the US is the most energy efficient country throughout the period and Canada the least. The constant logarithmic drift term clearly dominates these series so there is no apparent visual sign of a structural break in 1994. I also applied the convergence and structural break tests to these extracted series. As expected the Park and Sung test cannot reject the hypothesis that the technology trend has a unit root in each of the three countries (Table 1).

Also as expected there is no strong evidence for a structural break in the trend (Table 2). The beta convergence test (Table 3) shows that there is very weak convergence among the technology trends in the three countries. The effect of the initial condition may have a decreased effect in the post-NAFTA period, though the significance level of this difference is low. The average rate of decline accelerates after the introduction of NAFTA. The Strazicich and List cointegration test (Table 4) results in the acceptance of the non-cointegration hypothesis. In conclusion, while the technology is improving in all three countries there is little evidence for convergence in logarithmic terms across the countries and NAFTA has little effect on this situation.

Sulfur

Table 5 shows that the sulfur model also passes tests for whiteness of the residuals at reasonable significance levels and that the model explains a very high percentage of the variation in the dependent variable. A likelihood ratio test allows the rejection of the restriction that the observation errors are independent across the three countries at the 3% level. The regression type parameters for the sulfur model in Table 6 have some similarities and some differences with those estimated for a sample of fifteen OECD countries by Stern (1995). On the whole the values seem less plausible – in particular the very large positive coefficient on nickel refining and negative coefficients on lead refining and non-manufacturing industry. The coefficients are likely biased due to the small sample of countries with differing economic structures, which can induce spurious correlations. For example, the highest level of nickel processing occurs in Canada which also has the highest levels of sulfur emissions on either a per capita or per dollar of GDP basis, while the situation is exactly reversed in Mexico and the US has intermediate levels of both nickel processing and sulfur emissions. Also, all the coefficients should be interpreted on a *ceteris paribus* basis. Conditioned on primary fuel and metal smelting mix additional non-manufacturing industry could, conceivably result in less emissions *ceteris paribus*. Furthermore, all the parameters indicate the marginal contribution to sulfur emissions given the average state of pollution abatement associated with that variable across the sample. An input that already has a high degree of abatement associated with it may have an insignificant effect on emissions, irrespective of what its contribution might be in the absence of any abatement. The modeled state of technology can only model changes in the level of abatement relative to an unknown baseline. The returns to scale term show decreasing returns – as the inputs are increased by 1%, sulfur emissions increase by 1.07% *ceteris paribus*.

Table 7 shows that for the sulfur model the optimal estimate finds that the technology trends are I(1) (simple random walks) with constant drift terms. There is only one common stochastic shock shared by the technology trends in the three countries though the shocks in Mexico are negatively correlated with those in the US and Canada. Therefore we find that the trends cointegrate. The negative drift terms (Table 5 and Figure 14) show that the state of technology in sulfur emissions is improving in all three countries, so that in absolute terms there is convergence across the NAFTA region, but as the trends are more negative in Canada and the US there is not convergence in logarithmic or percentage terms. As mentioned above, restricting these drift terms to zero can be strongly rejected, which is again confirmed by the highly significant t-statistics on the individual slope components presented here in Table 5. Allowing for a structural break in 1994 in the shocks to the trend slopes does not result in non-zero estimates for these parameters.

Figure 14 presents the extracted technology trends for the sulfur model. The scale is arbitrary. According to these results the US emits the least sulfur *ceteris paribus* throughout the period. Canada starts the period as the "dirtiest" country and improves significantly. Mexico improves at a slower pace. The trends in the figure are not in logarithms. It is clear, though, that the linear drift component of the logarithmic trends dominates the random walk component.

I applied the convergence and structural break tests to these extracted series. As expected, the Park and Sung test cannot reject the hypothesis that the technology trend has a unit root in each of the three countries. Also as expected there is no strong evidence for a structural break in the trend. The beta convergence test (Table 3) shows that the sulfur technology trends are strongly converging but that the average rate of decline does not change after the introduction of NAFTA and the effect of the initial condition may have some increased effect in the post-NAFTA period, though the significance level is low. The Strazicich and List cointegration test (Table 4) rejects cointegration strongly. The Mexican technology trend consistently moves in the opposite direction to the Canadian and US trends relative to the mean. This result is a foregone conclusion as the Mexican logarithmic drift term is less negative than the drift terms of the other two countries. In conclusion, while the technology is improving in all three countries, the different tests give conflicting results for convergence in technology across the countries, but in either case NAFTA has no significant effect on the rate of technological change or on convergence.

Conclusions

The results of this study show that regarding air pollution and energy efficiency, none of the more extreme predictions of the outcomes of NAFTA have come to fruition to date. Rather, trends that were already present before NAFTA continue and in some cases improve post-NAFTA, but not yet in a dramatic way. This result is not surprising, as NAFTA represents a continuation of the liberalization process that began in Mexico in the 1980s.

There is strong evidence of convergence for all four intensity indicators across the three countries towards a lower intensity level. Though intensity is rising initially in some cases in Mexico, it eventually begins to fall post-NAFTA. Per capita measures for the two criteria pollutants also show convergence, but this is not the case for energy and carbon and these variables also drift moderately upwards. The state of technology in energy efficiency and sulfur abatement is improving in all countries, though there is little if any sign of convergence and NAFTA has no effect on the trend of technology diffusion. According to these results Mexico's technology is improving at a slower rate than its two northern neighbors'.

We can compare these results to those of the few studies that have examined the impact of NAFTA on economic convergence of the conventional sort among the NAFTA partners. Schiff and Wang (2003) find that trade with Mexico's NAFTA neighbors has had a large and significant impact on TFP in Mexico's manufacturing sector and that there is some convergence with the other North American economies. On the other hand, Madariaga *et al*. (2004) find divergence in income per capita among US and Mexican states using both β and σ measures of convergence but they find that when agglomeration within countries is taken into account there is significant conditional β- convergence. However, the rate of convergence seems unaffected by NAFTA. Similarly, Fernandez and Kutan (2005) find that the correlation between the business cycles in the three NAFTA countries was the same in the early 1980s as in the mid-1990s. These results are congruent with the results of the present study that whatever convergence is underway among the economies is not affected very much by the accession of Mexico to NAFTA. The relatively slow growth of the Mexican GDP per capita helps drive the convergence of the energy and emissions intensity variables and is reflected in the slow rate of technological change estimated in this paper.

However, as all three countries' populations have grown strongly some of the positive trends described above do not carry over to total emission loads (Figures 1 through 4). Therefore, environmental change has been more negative. But assuming that the population growth rate is exogenous to NAFTA this cannot be blamed on NAFTA.

Appendix: Data Sources

Pollution Emissions

Generally the emissions series I use were developed using bottom up methods, which are described in the sources I cite. I prefer to use the series developed by the governments in question as these generally rely on much more detailed information and more effort than the academic series (LeFohn *et al*., 1999; Marland *et al*., 2003) which were developed for all countries in the world over 150 year plus time periods. I also regard more recent estimates to be probably superior due to "learning by doing" at the agencies involved.

Carbon Emissions:

Canada: Data for 1971-1989 are based Marland *et al*. (2003). CO2 emissions for 1990-2002 are from Matin *et al*. (2004) and updated from the Environment Canada website for 2003. These data include non-energy related industrial emissions as well as energy related emissions but do not include emissions from land use change. The Marland *et al*. data for 1971-1989 are scaled up to reflect the higher level of emissions in the Matin *et al*. data. The OECD (2005) series is within 2-3% of the energy related emissions given by the Matin *et al*. series but the Marland et al. series is 4% below the Matin energy-related series in 1990, rising to a 22% gap in 2000.

Mexico: Data for 1971-1989 are from Marland et al. (2003). Data for 1990-2002 are from OECD (2005). No scaling is applied to the earlier data.

USA: Data for 1971-1989 are from Marland *et al*. (2003). CO2 emissions for 1990-2002 are from USEPA (2005). Differences between the different data sources are not very large in the case of the USA.

Sulfur Emissions:

Canada: Sulfur emissions for 1971-2002 are from OECD (various years).

Mexico: Data on SOx is available from *INEGI* (various years) for 1985-2003. For 1971-1984 the growth rates in the ASL database (ASL, 1997; Lefohn *et al*., 1999) were used to extrapolate back from the INEGI data. This implies that I believe that the INEGI data are more reliable, while I believe that the ASL data reasonably accurately reflects the rates of change of emissions in the earlier years.

United States: Data for 1971-98 are available from US EPA (2000) and updated to 2003 using data available from the EPA website.

NOx Emissions:

Canada: Data for 1980-2002 are from OECD (various years). Over time, earlier estimates of emissions have been increased and so I adjusted upwards the earlier data to splice smoothly to the more recent sources.

Mexico: Data available from INEGI (various years) for 1985-2003.

USA: Data for 1971-98 are available from US EPA (2000) and updated to 2003 from sources available from the EPA website.

Explanatory Variables and Energy Use

Complete series were compiled for all of the following variables for the period 1971-2003 for Canada, Mexico, and the U.S.

Energy Use:

Data are from the International Energy Administration (2003) and IEA online data. Data were collected for total primary energy supply of crude oil, refined petroleum products, natural gas, coal, hydropower, nuclear power, and biomass fuels. Other energy use categories were considered small enough to ignore. Primary supply of refined petroleum products is equivalent to actual end use oil consumption in a country while primary supply of crude oil is the quantity of oil refined in a country.

GDP:

I obtained the data from the Penn World Table version 6.1 (Heston *et al*., 2002). Data for 2001-3 are updated from the *World Development Indicators Online* published by the World Bank (2005).

Population:

Data are from the *World Development Indicators Online*.

Area:

Area data was obtained from *World Development Indicators Online*.

Economic Structure:

The structure of value added by industry was obtained from the *SourceOECD* website and *World Development Indicators Online*. 2001-2003 data for Canada was obtained from Statistics Canada (2005) and 2002-3 data for the US was downloaded from the Bureau of Economic Analysis website.

Metal Smelting:

Data on primary production of refined copper, lead, zinc, and nickel for 1980-2000 were received from the United Nations Industrial Development Organization. These data are reported in the *Yearbook of Industrial Statistics*. For copper, lead, and zinc we obtained the same data for 1971-1979 from the hardcopy version. For nickel we obtained data for 1971-1979 from the US

Bureau of Mines *Minerals Yearbook*. The latter source was used to fill any gaps in the UNIDO data, for all data in 2001-3, and for lead data for Mexico in 1990-2003.

Units as Entered into the Econometric Model

Sulfur: Thousands of metric tonnes of sulfur

NOx: Thousands of metric tonnes of nitrogen oxides

Carbon: Millions of metric tonnes of carbon

Energy: Millions of metric tonnes of oil equivalent

GDP and Industry Outputs: Billions of 1995 international US dollars

Population: Thousands

Area: Square kilometers

Metals: Thousands of metric tonnes

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Table 1. Park and Sung Unit Root Statistics

	Canada	Mexico	USA
Energy/P	-0.36601	-1.63505	0.00973
Energy/GDP	-0.2391	0.17999	-0.90995
A Energy	-0.72959	0.50536	-0.75476
Carbon/P	-0.07764	-2.34267	-0.02427
Carbon/GDP	-0.56054	0.13296	-0.85952
Sulfur/P	1.58759	-1.00351	-1.57097
Sulfur/GDP	1.21039	-1.00923	-2.40736
A Sulfur	-3.03292	1.89150	1.57157
NOx/P	-0.39465	-0.32175	-0.2959
NOx/GDP	-0.92779	-1.84444	-0.63778

Table 2. Structural Break Tests

	Canada	Mexico	USA
Energy/P	0.79495	-0.69035	-0.07093
Energy/GDP	-0.44981	-1.63003	-0.51523
A Energy	-0.57185	-1.08464	0.21887
Carbon/P	2.28982	-0.09798	0.40725
Carbon/GDP	0.40613	-1.05633	-0.53973
Sulfur/P	0.84956	-0.80493	-1.93413
Sulfur/GDP	0.09739	-1.00674	-1.9862
A Sulfur	-1.18220	1.17994	-1.17994
NOx/P	-0.35616	0.15483	-2.35752
NOx/GDP	-3.7493	-0.12953	-2.34738

Table 3. β-Convergence Regressions

	α	β	δ_1	δ_2
Energy/P	0.0102	-0.0120	-0.0354	0.0160
	2.2096	*-2.2147*	*-1.5616*	*2.3446*
Energy/GDP	-0.0074	-0.0308	-0.0125	0.0269
	-2.4196	*-4.4297*	*-2.1323*	*1.7100*
A Energy	-0.0074	-0.0112	-0.0125	0.0165
	-2.1102	*-1.2173*	*-2.0478*	*1.1318*
Carbon/P	0.0055	-0.0116	0.0004	0.0114
	1.0535	*-1.9009*	*0.0613*	*1.4237*
Carbon/GDP	-0.0120	-0.0278	-0.0037	0.0183
	-2.8138	*-2.9776*	*-0.5991*	*1.2700*
Sulfur/P	-0.0176	-0.0251	-0.0084	0.0215
	-2.0489	*-3.2169*	*-0.5816*	*1.5910*
Sulfur/GDP	-0.0352	-0.0407	-0.0127	0.0311
	-4.5336	*-3.6881*	*-0.9895*	*1.8393*
A Sulfur	-0.017	-0.0156	2.87E-04	-8.60E-03
	-12.5263	*-5.9068*	*0.0996*	*-1.5254*
NOx/P	-0.0018	-0.0112	-0.0041	-0.0099
	-0.4951	*-3.1523*	*-0.4610*	*-0.9670*
NOx/GDP	-0.0114	-0.0301	-0.0163	-0.0102
	-2.9379	*-6.2859*	*-2.3161*	*-0.9238*

Note: t-statistics are in italics.

Table 4. Strazicich and List Cointegration Test

	ADF(3) full period	DF full period	DF pre-NAFTA	DF post-NAFTA
Energy/P	-4.79285	-5.02876	-0.88805	-0.59343
Energy/GDP	-4.47285	-4.36136	-0.23482	-2.67573
A Energy	-1.22699	1.60274	4.05947	-0.60359
Carbon/P	-5.34817	-4.22166	-0.66582	0.18266
Carbon/GDP	-6.52864	-2.76926	0.01584	-0.96668
Sulfur/P	-4.61205	-3.27023	-0.86442	-2.21813
Sulfur/GDP	-4.36008	-1.92497	-0.19412	-3.77367
A Sulfur	5.20038	6.07660	-1.47023	0.76350
NOx/P	4.34461	8.91437	3.22131	3.23997
NOx/GDP	7.62648	8.29985	-2.26952	2.89619

Table 5. Frontier Models: Diagnostic and Trend Statistics

	Slope Estimate	Standard Error	t-Statistic	p Q(1)	p Q(8)	R-square
Energy Model						
Canada	-0.0204	3.59E-03	5.68	0.61	0.56	n.a.
Mexico	-0.0127	2.52E-03	5.04	0.34	0.10	n.a.
USA	-0.0252	1.63E-03	15.46	0.49	0.36	n.a.
Sulfur Model						
Canada	-0.0421	3.60E-03	-11.68	0.63	0.04	0.9825
Mexico	-9.49E-03	1.58E-03	-6.00	0.83	0.18	0.9843
USA	-0.0382	5.25E-03	-7.28	0.82	0.28	0.9981

Table 6. Frontier Models: Parameter Estimates

	Energy		Sulfur	
Variable	**Coefficients**	**t-statistics**	**Coefficients**	**t-statistics**
Coefficients w.r.t. fuels				
Coal	0.1000	1.9103	0.03118	17.3148
Oil	0.1154	4.9275	0.00216	1.662
Natural gas	0.1041	3.6587	-0.00102	-0.5872
Hydro	0.3075	3.7969	9.80E-04	0.1351
Nuclear	-0.0569	-1.6001	-0.00384	-0.8704
Biomass	0.4299	n.a.	0.0037	1.5598
Coefficients w.r.t. other commodity production:				
Oil refining			0.00407	6.6929
Copper			0.19513	2.0713
Zinc			-0.22843	-3.276
Lead			-0.47014	-11.6613
Nickel			1.4662	n.a.
Output elasticities w.r.t. to industries				
Agriculture	0.0451	n.a.	0.03706	n.a.
Non-manufacturing				
Industry	0.0031	0.2361	-0.07958	-1.7075
Manufacturing	0.2740	8.2520	0.0434	0.8046
Services	0.6778	30.3142	-8.73E-04	-0.0216
Returns to scale in inputs				
	-0.7768	-10.9361	1.07482	52.4795

Table 7. Frontier Models: Covariance Parameters

Parameter	Energy Model		Sulfur Model	
	Coefficient	t-statistic	Coefficient	t-statistic
Error Covariance Matrix				
G_{11}	8.69E-03	-1.9930	0.0401	9.3461
G_{21}	6.94E-03	-1.4838	-0.0216	-2.2115
G_{22}	0.0112	3.6274	0.0409	9.4569
G_{31}	5.20E-03	1.4327	-6.92E-03	-1.5934
G_{32}	7.47E-03	3.4198	4.67E-03	0.9749
G_{33}	0	n.a.	0	n.a.
Trend Shock Covariance Matrix				
H_{11}	0.0202	5.7678	0.0196	4.0597
H_{21}	1.14E-04	0.0336	-7.29E-03	-1.0565
H_{22}	0.0142	5.4470	0	n.a.
H_{31}	6.06E-03	2.4992	0.0292	15.2831
H_{32}	-6.87E-03	3.8155	0	n.a.
H_{33}	0	n.a.	0	n.a.
H_{44}	0	n.a.	0	n.a.
H_{54}	0	n.a.	0	n.a.
H_{55}	0	n.a.	0	n.a.
H_{64}	0	n.a.	0	n.a.
H_{65}	0	n.a.	0	n.a.
H_{66}	0	n.a.	0	n.a.

Notes: G is the Choleski factor of the error covariance matrix where the covariance itself is given by GG'. Similarly H is the Choleski factor of the trend shock covariance matrix. The three countries are numbered alphabetical order, Canada first and USA third.

Figure 1.

Figure 2.

Figure 3.