The Incidence of International Agreements: Do Latecomers Lose Out?

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Abstract:

The provision of an international public good, such as the ozone layer, is often pursued by means of the imposition of a uniform standard (such as the global ban on CFCs implemented under the Montreal Protocol). Many argue that uniform standards discriminate against the latecomers to development, since early adopters of the technology generate the emissions that cause the environmental problem while late adopters experience the same penalty with none of the earlier benefits. Others argue that latecomers benefit from technological changes that have occurred in the interim, and so incur little real change from disallowed technologies. This paper attempts to develop an objective framework for assessing the incidence of the costs of such uniform standards in the context of technological change. We formulate the principle of "development-based reciprocity": each country being held to the same level of contribution at the same level of development. The principle is shown to give concrete results in ascertaining the physical incidence of a uniform standard across heterogeneous countries, and provides a baseline for the examination of the critical issues regarding the valuation of the incidence of such standards within the context of technological change.

We would like to acknowledge the research assistance provided in the development of the database for this project by Jose Carlos Fernandez and Dylan Sutherland, Department of Applied Economics, Cambridge University. We would also like to acknowledge the input from Francesco Bosello in the development of the model. The underlying analysis is contained within the report attached under the title "The Impact of the Montreal Protocol: A Kuznets Curve Analysis of Ozone Depleting Substances" (hereinafter referred to as the technical report). We would also like to acknowledge the cooperation of several other bodies providing data, including the industry association AFEAS, the United Nations Environment Program, the US Department of Commerce and many individuals.

1. The Incidence of International Agreements

There are as many different approaches to fairness in the negotiation of international environmental agreements as there are states in the negotiations. Late developing states will argue that problems of resource despoliation are the result of developed country despoliation. Developed states will argue that latecomers have the benefits of new information and new technologies. All states will argue that others must shoulder more of the burden of the international agreement. The current conflict in the negotiations over the Kyoto Protocol is illustrative. The US argues that it will not join this agreement until the developing countries are bound under it. The developing countries argue that they will not undertake binding commitments since the problem is the consequence of developed countries' prior development. Other developed countries (e.g. EU) argue that new technologies and the Clean Development Mechanism should be used to bring developing countries into the fold. And nothing can move forward until the parties agree on the basis for distributing the costs of the agreement.

In this paper we set out to develop an objective basis for assessing the incidence of international environmental agreements. Uniform standards are often used because of their basic appeal to the universal notion of fairness or equity; however, uniformity must take into consideration different states' positions within inherently dynamic processes. The process of development is a dynamic one that places many different states at many different points within that process, and an understanding of what is common and what is different for states at different points within this process is critical.

Here we develop a dynamic notion of fairness that we term "development-based reciprocity". This standard merely requires that states at the same point in development shoulder the same burden in the conservation of common resources or capital. We then conceptualise the development process as a portfolio balancing process, in which each state must make the choice as to how it will accumulate productive capital and conserve environmental capital. This physical accumulation process exists independent of time and technology, and it provides a baseline against which to assess different states' positions at the same point in time.

We are able to assess this baseline by reference to the first-developing states' choices. There is little reason to expect a priori that later developing states would make systematically different choices regarding the fundamental balance between production and environment, and it is this expectation that provides the possibility of a baseline. This baseline then may be used to afford latecomers the same basic entitlements (or choices) as were self-selected by the first-developing states.

There are other processes that do exist within time, such as technological change. The first-developing states might initiate processes of technological change that afford new or better choices to the later-developing states. We examine this possibility and find that, if the fundamental distinction between states is portfolio re-balancing, technological change does not alter these choices systematically (at least not in favor of the environment). Latecomers remain entitled to the same baseline as that acquired by the first-developing states.

In the final two sections of the paper we estimate the physical incidence of the Montreal Protocol as a case study in the application of this principle, and then we demonstrate how this incidence might be valued. We find that, despite the vastly disproportionate physical incidence of the Montreal Protocol on developing countries, the value of this incidence is greatly reduced by the provision of adequate notice of the change in path. Latecomers do not lose out if they are compensated adequately far enough in advance.

2. Environment, Development and Technological Change: Developing Development-based Reciprocity

In this section we present a simple theoretical framework describing the manner in which the level of environmental management is chosen over time, and the factors on which it depends. Then we wish to incorporate various forms of technological change, in order to see how technological change would affect a country's trade-off between environmental management and consumption. The model builds on that of Stokey (1998), and it provides the theoretical justification for the empirical analysis of section 3.

In this section we wish to describe the path of management that would be pursued within a regime of *unilateral management* – that is, the trade-off between consumption and environmental protection that is pursued will be based solely on a country's own perceived self interest. We will assume that, even if production involves the use of common resources, the self-interest of a country will nevertheless indicate that some level of self-provision of the public good would occur. (Varian, 1992; Murdoch and Sandler, 1997). One of the abstractions that we will employ here will be to ignore the effect of other countries' choices on that own self-interest.[1] (Barrett, 1994; Hoel 1991) The reason for this is that we are attempting to model the choice that latecomers *should* make in regard to the provision of the public good, not the choice that latecomers *would* make in the event that it was still being provided under a regime of unilateral management.

Suppose that a country has to choose between consumption c and the level of expenditure on environmental management (M) to maximize (discounted) inter-temporal utility. This society is making this choice on the basis of a fundamental trade-off between consumption benefits and the dis-benefits resulting from environmental damages. Technology is such that production using a particular capital stock (k) results in both a flow of goods and services (that may be either consumed or reinvested in that capital stock) but also contributes to a common stock of pollution X.

The way in which a society trades-off between consumption benefits and pollution disutility is captured in a separable welfare function, in which the elasticity of consumption is represented by the exponent $(1-\sigma)$ while the harm emanating from environmental damage is represented by the exponent γ. A scalar (B) allows for differential weighting between the consumption and environmental sectors. For our purposes, we will assume that these parameters are not country-specific "taste" parameters, but that they may be considered to be "fixed" parameters across societies in some fundamental sense. This is the meaning of the concept of *development-based reciprocity* mentioned previously; the estimation of these parameters for early-developing states may be taken as an indicator of the standard to which later-developing states may be held.[2]

The particular context we are considering is that part of any society's economy that produces or consumes refrigeration. Least-cost production currently involves the use of highly stable chemical compounds (such as CFCs and their closest substitutes). The use of such compounds implies the degradation of the outer layers of the atmosphere (i.e. ozone) and hence increases the level of radiation at the surface of the earth. The fundamental trade-off in the refrigeration sector therefore involves lowest-cost cooling versus long-term health effects (e.g. cataracts and skin

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[1] Of course, the provision of public goods by other agents would impact on a country's own choice, but we abstract from this issue here on the grounds that our empirical work observes the level of unilateral management occurring by the *first countries* to engage in management. At that point considerations of free riding (on others' prior provision) are assumed to be less dominant. This establishes a baseline for what we find to be a developing country's "own interest" based on own impacts.

[2] This is the basic point of this paper. It is assumed that a first-developing country's trade-off under conditions of unilateral management may establish a baseline for the highest level of management to which latecomers may be held.

cancers). We will term the consumption benefits from capital investment (F(k)) and the countervailing health benefits from pollution investment (H(X)). Clearly, the poorest societies (with life expectancies far below the ages of onset of such old-age problems) may select very different choices regarding this trade-off than would the richest.

The dynamics of the problem allow us to consider the manner in which technological change might affect this trade-off over time. The problem is constrained by the two laws of motion for capital and own-contributions to pollution stocks, $\dot{k}$ and $\dot{X}$ respectively.[3] The production technology is Cobb-Douglas with share $0<\alpha<1$ for capital, technological change occurs at the constant rate $g>0$, capital depreciates at the constant rate $\delta \geq 0$.

The societal problem then is to:

$$\underset{c,M}{Max} \quad \int_0^\infty e^{-\rho t}\left[\frac{c^{1-\sigma}}{1-\sigma}-\frac{B}{\gamma}X^{\gamma}\right]dt \qquad (2.1)$$

s.t. $$\dot{k} = Ae^{gt}k^{\alpha}(1-M)-\delta k-c \qquad (2.1a)$$

$$\dot{X} = Ae^{gt}k^{\alpha}(1-M)^{\beta}-\eta X \qquad (2.1b)$$

given the initial conditions $k(0)=k_0$ and $X(0)=X_0$ and $B>0$, $\beta,\gamma>1$, $M \in [0,1]$.

For our purposes, the important control variable is $M \in [0,1]$ which represents the share of production diverted toward environmental management. It is the control variable determining the trade-off between consumption and environmental goods and services. When M is at its lowest level, the highest production is allowed, but the highest environmental damage is also experienced; on the other hand, an M equal to one will reduce the country's contribution to the pollution stock by the maximum amount, but will not allow for any production or consumption activities.[4]

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[3] The model is a simple Ramsey-type growth model specialized to a constant-elasticity utility function with additively-separable exponential environmental damage. Technical progress is exogenous, as we are considering the incidence of the management regime rather than the incentive effects.

[4] $\eta \geq 0$ is the natural decay rate of pollution stock.

A) Optimality Conditions, No Technological Progress

The first order conditions for this problem yield:

(2.2)

c^* : $c^{-\sigma} = \lambda$ (2.2a)

M^*: $\lambda - \mu\beta(1-M)^{\beta-1} \geq 0$, with equality if $M > 0$ (2.2b)

$$M = \begin{cases} 0, & \text{if} \quad \lambda \geq \mu\beta \\ 1-(\lambda/\mu\beta)^{1/(\beta-1)}, & \text{if} \quad \lambda < \mu\beta \end{cases}$$

k^*: $\dot{\lambda} = (\rho+\delta)\lambda - \alpha A e^{gt} k^{\alpha-1}(1-M)(\lambda - \mu(1-M)^{\beta-1})$, (2.2c)

[k^{*ss}: $F'(k)-H'(X(k))=\rho+\delta$]

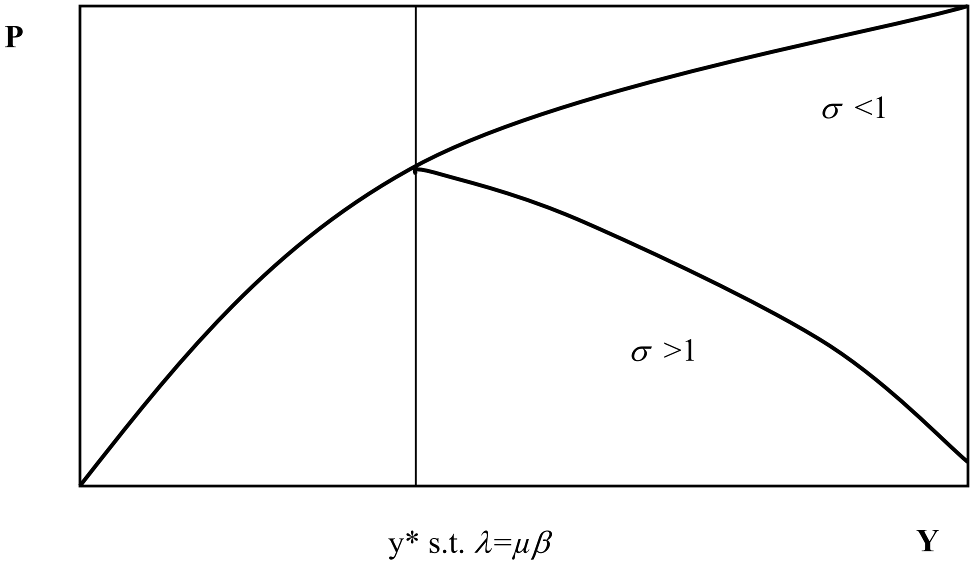
x^*: $\dot{\mu} = (\rho+\eta)\mu - Bx^{\gamma-1}$ (2.2d)

(where λ and μ are the costate variables for *k* and *X).*

M determines how the society separates between the production of environmental and consumption goods and services. (2.2b) Given the bounds on *M*, note that when $\lambda \geq \mu\beta$ we get a corner solution with *M* =0, that is no resources are devoted to abatement activity and pollution is not managed. As usual λ and μ are the shadow prices of capital and pollution respectively; when the first is sufficiently high compared to the second it is optimal to pursue production and consumption and accept an uncontrolled environmental damage. When $\lambda < \mu\beta$ optimality implies $M = 1-(\lambda/\mu\beta)^{1/(\beta-1)} > 0$, that is when environmental damage is high enough the scarce environmental resource becomes valuable enough to be subject to increasing management.

Proposition 1: Substitution between Consumption and Environmental Goods & Services in Development. If an undeveloped country is assumed to be one that has relatively high levels of environmental capital (low levels of emission stocks) and low levels of production capital, then that country will pursue a development path that will drive environmental capital lower and physical capital higher until returns from the two stocks are equalized.

It is reasonable to suppose that (for an undeveloped country) initially both the capital and pollution stocks are small. Accordingly marginal benefits from production are high and marginal damages from pollution are low. As development continues, pollution and capital stocks increase, thus along the transition path μ rises, λ falls so that λ/μ declines monotonically. Therefore a development or income threshold can be identified, reflected by the condition $\lambda/\mu\beta = 1$ in (2.2b), before which no management is optimal (*M*=0) and after which increasing resources are employed to abate (*M* increases monotonically) (see fig.2). Both the inflow of new pollution and the stock of pollution rise before the critical date. After this point, the pollution flow increases more slowly than output. This is a "weak de-coupling" between environment and growth induced by management. This indicates the basis for the belief that management becomes optimal even from a "unilateral" perspective after a critical threshold (see also Selden and Song (1995) for similar treatment).



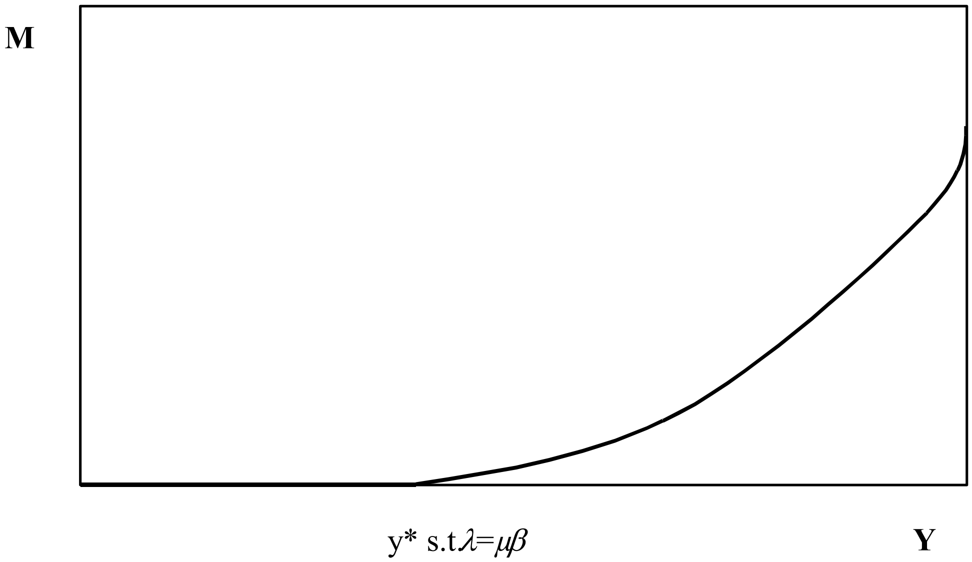


Figure 1: Share of resources to Management

Figure 2: Development and Pollution

The dynamic conditions for the optimum indicate the way in which the society will accumulate stocks of capital and pollution. The optimal condition for stock of capital (k*) indicates that the society will accumulate capital (in the steady state) to the point where the productivity of capital in the production of consumption goods benefits (F'(k)) less its productivity in the implicit production of health disbenefits (-H'(X(k)) is equal to the return on capital generally ($\rho+\delta$). (2.2c) The same is true for the accumulation of the optimal stock of pollution (X*); the optimal stock sets the optimal production of health benefits (H'(X)) equal to the return on capital ($\rho+\eta$). (2.2d)

In this model the society is considering both environment and physical capital as alternative capital stocks, and the choice of consumption level determines both levels and shares of the different types of goods. The choice is determined fundamentally by equilibrating returns between the different forms of capital, and the choice of management level is the control variable that enables the society to drive the various capital accounts upwards (downwards) toward equilibrium. In general, a developing country (starting from low levels of capital and consumption goods) would be expected to follow the path in Figure 2, driving environmental capital downwards while accumulating physical capital to reach equilibrium.

In this scenario, the choice between environmental management and consumption is driven by the societal trade-off between health benefits and consumption benefits and it is stationary across time and technological change (as modelled here). The sole criterion that determines individual country decision-making is the level and form of capital accumulation that has been achieved by that state.

The importance of the optimality conditions derived in part A of this section is that they are time independent. These conditions indicate how much a state would contribute management to the conservation of environmental stocks (in its own perceived self-interest) given its current stage of development, where development is a physical portfolio-balancing process. If it is assumed that states have an equal right to an equal share of common environmental goods (such as the global atmosphere) irrespective of when they commence this development process, then each state would follow the same management/development path and the time at which they commence development is an irrelevance.

Proposition 2: Latecomers and Development-based Reciprocity. In the absence of technological change, each state would trade-off environment and consumption in the same manner and in accordance with its current stage of development (where development is a physical portfolio-balancing process). So long as it is assumed that each state is entitled to an equal share of global common resources, this would be the case irrespective of the time at which that development process occurred or the order in which states developed. Under this *development-based reciprocity* each state recognizes every other state's right to an equal share of global resources as well as every other state's obligation to contribute in accordance with its stage of development.

This principle provides a physical measure of the incidence of uniform standards in international environmental agreements. The incidence of the Montreal Protocol under this standard is set forth in section 3A. There we show that the impact of the uniform ban of CFCs places most of the incidence of the Montreal Protocol squarely on the shoulders of the least developing countries.

B) Optimality Conditions, Environment-Neutral Technological Progress

Does the passage of time matter? That is, does it matter that some states have followed their development paths at an early point in time than others will? There are two possible meanings to this contention. One is that early-developing countries had less information than later-developing countries, and so exploited some global resources incidentally rather than purposely. The second meaning is that later-developing countries will face different trade-offs on account of technological changes that alter the prior analysis. This is the issue we address here.

There are two distinct approaches toward technological change considered within this model, both are modeled by causing growth (g) to be tied exponentially to the passage of time (e^{gt}). The first approach involves greater production for the same level of capital, but with equivalent growth in emissions per unit of output. This form of technological progress enables the more rapid movement along the development path, but not any change in the fundamental trade-off between consumption and environment. This form of technological progress we term *environment-neutral*. This is modeled by means of applying the same process of technological change to both sides of the economy: production and environment. The second form of technological progress enables more production from the same capital stock but without increasing emissions; this we term *environment-saving technological progress*. We model this by means of applying the autonomous process of technical change only to the production side of the economy (without increasing emissions on the environment side). (see following subsection)

Considering first the same model above, but with the environment neutral technological progress incorporated into both of the equations of motion.

Equations of Motion, Environment-Neutral Technological Progress

$$\dot{k} = Ae^{gt}k^{\alpha}(1-M) - \delta k - c \qquad (2.1a)$$

$$\dot{X} = Ae^{gt}k^{\alpha}(1-M)^{\beta} - \eta X \qquad (2.1b)$$

Optimality Conditions Given Environment-Neutral Technological Progress

All optimality conditions remain unchanged but for:

k^{*EN}: $\dot{\lambda} = (\rho+\delta)\lambda - \alpha Ae^{gt}k^{\alpha-1}(1-M)(\lambda - \mu(1-M)^{\beta-1})$, (2.2cEN)

[i.e. k^{*ss}: e^{gt} [F’(k)-H’(X(k))]=$\rho+\delta$]

The impact of general technological change is to make it possible for the “latecomer state” to accumulate more productive capital in its final portfolio. The amount of environmental capital in that portfolio remains the same, but more productive capital is now possible given the enhanced productivity of that form. Since environmental capital remains of the same relative value, the point at which management commences M* remains the same.

Proposition 3: Latecomers under Environment-Neutral Technological Change. Latecomer states under environment-neutral technological change would follow the same path of capital accumulation and portfolio balancing as earlier states, but latecomer states would continue to accumulate physical capital beyond the point at which states would have in the absence of technological change. The impact of technological change is to reduce the impacts of physical capital accumulation over time, and thus to enable a greater accumulation of physical capital in the final portfolio.

C) Optimality Conditions, Environment-Saving Technical Progress

What if latecomers are benefited by the creation of a process that enables development with less environmental impact? This might result if the early developing states invest in the creation of such forms of technological change, after they have exploited the common environmental resource. Then the process of technological change might take a form that is biased towards saving environmental capital.

This alternative specification for technological progress might be modeled as autonomous change within the capital sector that has no impact on the environment side of the economy. This is the polar example of resource-augmenting technological progress; in this case the technological change is *environment-saving* in that production increases without any impact on the environment. In effect, the productive side of the economy is able to generate increased production per unit of physical capital without making increased demands on environmental capital.

Equations of Motion, Environment-saving Technical Progress

$$\dot{k} = Ae^{gt}k^{\alpha}(1-M) - \delta k - c \qquad (2.1\text{aES})$$

$$\dot{X} = Ak^{\alpha}(1-M)^{\beta} - \eta X \qquad (2.1\text{bES})$$

With environment-saving technological progress, the first order conditions for M and k are altered to recognise the differential impact of technical progress between the sectors.

First Order Conditions, Environment-saving Technical Progress

$$M^{*ES}\text{:}\quad \lambda e^{gt} - \mu\beta(1-M)^{\beta-1} \geq 0, \qquad \text{with equality if } M > 0 \qquad (2.2\text{bES})$$

$$M = \begin{cases} 0, & \text{if} \quad \lambda \geq (\mu\beta)/e^{gt} \\ 1-(\lambda e^{gt}/\mu\beta)^{1/(\beta-1)}, & \text{if} \quad \lambda < (\mu\beta)/e^{gt} \end{cases}$$

$$k^{*ES}\text{:}\quad \dot{\lambda} = (\rho+\delta)\lambda - \alpha Ae^{gt}k^{\alpha-1}(1-M)(\lambda - (\mu(1-M)^{\beta-1})/e^{gt}) \qquad (2.2\text{cES})$$

$$k^{*ss}\text{: } F'(k) - H'(X(k))/e^{gt} = (\rho+\delta)/e^{gt}$$

This form of technological change provides for two different optimality conditions. First, (2.5bES) indicates that the investments in M become less worthwhile with the passage of time, since the costs of production are reduced with the passage of time (by exogenous technical progress); the latecomer state will actually defer the point in time at which M is invoked.

Second, the relative benefits from increased capital stock accumulation (2.5cES) result from the fact that there are reduced health costs (with time) flowing from capital accumulation. Therefore, the new optimality conditions indicate that, with environment-saving technological progress, the society would undertake less abatement over the same amount of time, and accumulate more physical capital (relative to environmental capital) in the steady state.

Proposition 4: Latecomers and Environment-Saving Technological Change. Latecomer states under environment-saving technological change would follow the same path of capital accumulation and portfolio balancing as earlier states initially, but latecomer states would invoke environmental management later in the process and would also continue to accumulate physical capital beyond the point at which states would have in the absence of technological change. The impact of environment-saving technological change is to reduce the impacts of physical capital accumulation over time, and thus to both substitute for management and to enable a greater accumulation of physical capital in the final portfolio.

Conclusion: The Incidence of International Agreements

The model shows the manner in which societies will trade-off between environmental services and consumption goods in the process of development. It has argued that this trade-off is a fundamental part of the developmental process, during which states re-balance their portfolio of productive and environmental capital. It has also argued that this process should be considered to be stationary across states and across time, and thus would apply equally to any country at any other point in time. If each state has an equal right to an equal share of common resources, then the physical incidence of a uniform standard may be assessed by reference to the trade-off made by the first developing states in their use of this environmental capital and extending the same right to latecomers (*development-based reciprocity*).

The second result is the impact of technological change on societal decision making regarding this portfolio balancing process. Although it has been argued that technological change provides a reason for latecomers to make less use of the environmental good, this model indicates that the opposite is the case. Environment-neutral technological progress allows latecomers to accumulate capital along the same path, but provides more incentive to accumulate more physical capital as it becomes more productive. Environment-saving technological progress acts as a substitute for management, enabling the latecomer to both defer management and to accumulate more physical capital over time. If development is fundamentally about the re-balancing of capital portfolios, technological change merely alters some of the flows of costs and benefits from those capital stocks.

3. Estimating the Development-based Reciprocity Baseline

In this section we will estimate the relationship between income and CFC production in the era of CFC use by first-developing states, and then extrapolate this behavior to the latecomers to CFC usage. In this manner we will be able to generate forecasts the expected level of CFC use by latecomers with that required by the international agreement. This is the manner in which we will estimate the physical incidence of the Montreal Protocol.

The period we will analyze to ascertain this trade-off coincides with the period of unilateral management by developed countries (i.e. before the Montreal Protocol).

Stages of Ozone Management and Regimes:

Stage I	**Stage II**	**Stage III**
Non-Management	**Unilateral Management** **Non-coop. Behavior**	**Joint management** **Cooperative Behavior**
1930s	**Mid-1970s**	**1/1/89**
Invention of CFCs	**Discovery of Ozone Depletion**	**Management under Montreal Protocol**

This timeline breaks up the history of ozone depletion and management neatly into the three distinct periods: I) non-management (1930-1973); II) unilateral management (1974-1988); and III) joint management (1989 onwards). It is during the second period that the first-developing countries commenced management of CFCs according to their own perceived state-interest. It is the examination of the level of management applied by states in this period on which we will build our baseline of development-based reciprocity. In short, we have argued that no state, irrespective of its time of development, should be held to a higher standard than that self-imposed by the earliest developing states. Estimating that self-imposed obligation is our task in this section.

3.1 Data and Sources

An immediate problem confronting any empirical research of CFC use is a lack of data.[5] Global CFC production figures are produced by the industry association AFEAS (see AFEAS (1995)); commercial confidentiality means, however, that country-level production is not available for any reasonable time period.[6] In addition, trade data (so that consumption can be calculated) are available only at an aggregate level. The appendix describes how these problems have been tackled in this paper, and the limitations of the final data sets that have been constructed. Our approach is based on disaggregation via the use of observable surrogates for the unobservable CFCs; this approach is consistent with that which has been used in the only other attempts to construct a CFC database (WRI 1990, 1992). The second major problem confronting the researcher is how to convert consumption (of raw chemicals or end-products containing CFCs) into emissions. The chemical stability of CFCs means that all CFCs produced will, eventually, reach the stratosphere. But there will be a lag between consumption of the chemical (either in raw or end-product form) and release to the environment. For the purposes of this analysis, this

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[5] To our knowledge the only other attempt to create a database of CFC emissions has been undertaken by the World Resources Institute. (WRI 1990, 1992) In discussions with the authors of that data base, we have found that they have used the same sources and conducted the same exercises to reconstruct the data. We have redone these exercise in order to create a consistent and current data base and in order to be transparent concerning the manner in which it was constructed. See Appendix A.

[6] Production and consumption figures are collected at a country level by the United Nations Environmental Program (UNEP) as part of the Montreal Protocol monitoring system. Only one year's data (1986) are available before the signing of the Protocol. The confidentiality requirements of UNEP do not allow the public dissemination of disaggregated data.

lag (which can be substantial) will be ignored. It is assumed that a country "cares" about the impacts of its current emissions in the year in which their production or consumption occurs.

A data set was constructed: production and prices of the raw chemicals CFCs 11 and 12, and income for 58 countries over the period 1976 to 1988 inclusive[7]. Details of the data and sources are contained in Appendix A. Summary statistics are shown below. Historic population and income data are taken from the Penn Mark V.6 World Tables (see Summers and Heston (1991)). The series on real per capita GDP is used to allow real comparisons between countries over time.

Table 1: Summary Description of Production Dataset (see appendix A for detail)

Variable	Mean	Standard Deviation	Minimum	Maximum
CFC Production Dataset (29 countries				
GDP per capita 1986 USD 100s	7.4088	4.5571	1.1240	17.7100
CFC Production p.c. Tonnes ODP	4.6403	4.8571	0.0667	34.1161
Source: See Appendix A	ODP stands for ozone depleting potential	CFC 11 and 12 have equivalent ODPs (1).	Note that the countries in data set 2 are not the same as in data set 1.	

3.2 Estimated Model

We estimate a reduced-form model using only the most important variables determining national CFC production and consumption. The estimated parameters of this model can then be used (with forecasts of the independent variables) to produce forecasts. The reduced-form model that is used in existing Kuznets curve literature is usually static, but we formulate a dynamic model:

Estimation of Dynamic Model of CFC-Income Relationship:

(3.1)

$$cfc_{it} = \alpha_i + \gamma_t + \beta_3 y_{it} + \beta_4 y_{it}^2 + \beta_5 cfc_{i,t-1} + \varepsilon_{it}$$

Where:

cfc_{it} is CFC consumption or production per capita for country i in year t;

y_{it} is GDP per capita for country i in year t;

α_i is a fixed effect for country i[8]

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[7] Gaps in the data mean that regressions can be performed on only 29 countries.

[8] This might include exogenous factors such as the climate and geography of each country. For example, ozone depletion is of greater concern for countries which lie close to the poles; and so alpha i should be smaller for these

γt is a fixed effect for year t;[9]
$\beta_{1,2}$ are the independent variable coefficients.
and ε_{it} is a white noise error term for country i and year t.

Equation (1) is known as a two-way error component model; see Hsiao (1986). Most notable about the equation is the inclusion of income y as the only explanatory variable. The underlying assumption is that only income is truly exogenous—all other potentially relevant variables (such as the composition of output, political structure, etc.) are endogenous consequences of income growth. (Any other factors which might affect CFC consumption will be picked up in any event by the constants alpha i and gamma t. The functional form used—a quadratic in income—reflects the hypothesis that production/consumption per capita will grow at low income levels, and decline at higher wealth. It is expected that beta 1 will be greater than zero and beta 2 < 0; the critical level of income then equals beta 1 divided by twice beta 2. The specification includes lagged CFC production/consumption as a regressor in order to capture the effects of business cycles and feedback effects. Estimation of equation (1) using standard panel data techniques (the Within estimator) would yield biased and inconsistent results for panels of finite length; see Nickell (1981). Consequently, instrumental variable methods must be used. Following Arellano and Bond (1991), the orthogonality conditions between lagged values of y it and the disturbances μit are used to construct 'internal' instruments.[10] This study reports the estimation of equation (1) for CFC production.[11] Since it is anticipated that there will be correlation between the country fixed effects (γi) and the regressor x_{it} (since rich countries tend to be non-equatorial), only fixed effects estimation is performed.[12]

3.3. Estimation Results

All regressions reported in this section were performed on CFC production data over the period 1976-1988 for 29 countries. The dependent variable is total production of CFCs 11 and 12 (in tons), divided by population. Income variables are per capita in 1986 US$000s. The details of the data are given in appendix A.

Table 2 reports the results of estimating equation (1) using the instrumental variable method of Bond and Arellano (1991). (The data are first-differenced, so there are no country dummies.) The variable CFC1 is CFC production lagged one period. The results show that this variable is highly significant, with a coefficient of 0.3 and a t-statistic of 7.8. The coefficients on the linear and quadratic income terms are significant at the 92% and 87% levels, respectively. The improved statistical significance of the regression provides a justification for the use of a dynamic, rather than static, model. The critical income level in the Kuznets curve is *US$16,050*

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countries than for equatorial nations. Inclusion of this term avoids the biasedness and inconsistency problems that would result if the assumption of homogeneity across countries were used (see Hsiao (1986)).}

[9] This will capture year-specific factors, such as oil price shocks.

[10] The estimations are performed using DPD, a set of programs written in GAUSS by Arellano and Bond. We are grateful to Steve Bond for providing the programs and assistance.

[11] The data quality for CFC prices and consumption do not warrant a fuller reporting of those results, but the estimations were conducted on these data as checks on the production model. The results were consistent with those reported in this study. For a more complete report on the empirical analysis of this problem involving both static and dynamic estimations and production and consumption data, see Mason and Swanson (2000).

[12] Random effects estimation can yield biased and inconsistent results in this setting; see Greene (1993).

(which is just within-sample—see table 1). As discussed in the introduction, existing studies have found lower turning point values (of around US$8,000 or less) for domestic pollutants, with much higher values for global pollutants such as carbon dioxide. The value found in this paper fits well with this trend. The income elasticity of production, calculated at the average values of the variables in the model (see table 1) is 3.0633 (short-run) and 4.3929 (long-run). The Sargan test indicates that the instruments are valid, and that the regression is not over-identified.[13]

Table 2: Estimation of Dynamic Panel Model (Equation 1)

Variable	Estimate	Standard Error
Constant	-0.3357	0.2229
CFClag1	0.3027	0.0390
GDP per capita	3.5643	2.0266
GDP per capita (squared)	-0.1111	0.0736
D79 (year dummies)	0.4988	0.2200
D80	-0.6699	0.2495
D81	1.3999	0.4524
D82	-0.2298	0.3442
D83	0.6079	0.1929
D84	0.8755	0.7467
D85	0.4868	0.1600
D86	-0.4493	0.6922
D87	-0.8419	0.3743
D88	0.3070	0.2502
Regression Diagnostics:		
Wald Test (joint significance)	173.314868 (3)	
Wald Test (Significance of dummies)	43.95436 (11)	
Test for second order serial corr.	-1.008 (29)	
Sargan Test	302.097070 (60)	
Number of countries	29	
Number of observations	316	

The results indicate the importance of undertaking a dynamic estimation for a Kuznets form of relationship.[14] The existence of an "inverted U" relationship between income and CFC production cannot be rejected, and the turning point in this relationship exists at the high income end of the dataset (i.e. around 16,000 1986 US$ per capita).

4. The Incidence of the Montreal Protocol

The object of the previous section was to estimate the relationship between income and CFC by the earliest producers of these chemicals. In sections 3 this task was accomplished at the level of

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[13] Both the static and dynamic models were run with variables in natural logarithms. Statistical significance was not improved in either, so the results are not reported here

[14] The significance of the estimation and the estimators were vastly improved by using this technique.

individual countries across a period of a dozen years. This section uses the results of section 3 to produce forecasts of CFC production along these same baselines up to the year 2050.[15] Results are reported in aggregate terms and with the countries grouped into income quintiles. The comparison of the requirements of the Protocol with the forecasted CFC production provides an indication of the physical incidence of the Protocol.

4.1 Production Forecasts

The forecasts are summarized in figure 1, which shows global (i.e. summed over the countries which were producing in 1988) production of CFCs 11 and 12 for each year over the period 1989 to 2050.[16] Three growth scenarios are presented. 'Medium growth' assumes that growth occurs according to equation; 'fast growth' adds 0.005 to the growth rate for each country in each year; 'slow growth' subtracts 0.005. Alternative growth scenarios are analyzed below.[17] The figure shows that there is little difference over the entire period between the medium and slow growth scenarios; the fast scenario departs from the other two during the periods 2000-2010 and 2038 onwards, when the quadratic income term causes production to fall sharply. Despite these differences, total production over the period in the three scenarios is very similar: 3.317, 3.439, 3.475 billion tons of ODP in the fast, medium and slow scenarios respectively. Global production in 2050 is a factor of between 2.3 (fast) and 2.8 (medium and slow) greater than its 1988 level.

Insert Figure 1 Forecast CFC Production (II into III), 1990-2050

Figure 2 shows how shares in global production vary over the forecast period for income quintiles. These quintiles are countries grouped together by income levels in 1988. The highest quintile includes countries whose incomes lie in the top 20% of the global income distribution; the fourth quintile includes countries whose incomes lie below the top 20% but above the top 40% of the income distribution; and so on.

Insert Figure 2 Distribution of Forecast CFC Production, 1990-2050

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[15] The method for forecasting individual country populations and incomes is taken directly from Holz-Eakin and Selden (1993).

[16] .An important omission is that production from new countries, not included in the original number, is not modelled. The effect of this omission is to bias downwards not only future CFC production, but also the production share of the lowest income countries (see figure 2).

[17] The year-specific fixed effects coefficients in equation (2) were not forecast, but set equal to their 1988 levels.

Table 4 shows which countries are in which quintiles[18], and also gives summary statistics for each.

Table 4: Countries in Production Data set and their Income Groupings

Quintile	Country	CFC Prod per capita (tonnes)	GDP per capita (000s 1988 US$)	Population (000s)
Lowest	Algeria	0.2025	2.7690	23758
	Brazil	1.7365	4.208	143803
	Colombia	1.1954	3.231	31189
	India	0.4413	1.729	171994
	Thailand	1.0013	2.972	54536
	Turkey	1.4046	3.419	53764
	Chile	0.6361	3.989	12748
	Nicaragua	0.0667	1.719	3401
	Peru	0.3218	2.724	20654
	Philippines	0.1572	1.676	58721
Second	Argentina	1.2425	5.349	31536
	Greece	3.7753	6.459	10004
	Korea	6.297	5.607	41975
	Mexico	6.0418	5.349	78933
	Portugal	4.0659	6.01	10287
	Yugoslavia	0.1283	4.944	23566
Third	Spain	5.1387	8.759	38809
Fourth	Denmark	0.1812	13.571	5130
	Finland	12.8623	13.377	4951
	France	10.5613	13.259	55884
	Germany	13.3336	13.456	61474
	Hong Kong	2.7864	13.969	5627
	Italy	7.998	11.918	57452
	Japan	9.0302	13.156	122613
	Sweden	9.7743	14.408	8436
	UK	1.658	12.969	57065
	Norway	9.1505	14.674	4209
Highest	USA	7.5677	17.710	246307
	Canada	7.6776	17.258	25950

Figure 2 explains, for the medium growth scenario, the shape of the curve in figure 1. For example, the share of the lowest income quintile increases from under 20% at the beginning of the period to over 75% by the end; the highest two income quintiles account for over 65% of

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[18] Quintiles were defined by taking the largest income level in the sample and dividing it into five equal parts – countries are then listed with those that fall within the same income grouping. This definition preserves income proportionality, but allows populations in each quintile to vary. Despite this, each of the quintiles is relatively proportionate to its representation in the global population, except that the absence of China from the data set (and the disproportionate representation of western countries) provides an imbalance in world population toward the higher quintiles.

global production in 1988, but produce nothing by 2050. The monotonic fall in production by the higher income countries causes the fall in global production during 2007-2015; the relentless rise in production by the lower income countries maintains the overall upward trend. It is the low incomes and high populations of those countries in the lowest income groups that drives the continued use of CFCs throughout the forecast period.

4.2 The Physical Incidence of the Montreal Protocol

The physical incidence of the Montreal Protocol can be illustrated by considering figures 3 and 4, which are the analogues of figures 1 and 2 with countries' production replaced by their Protocol obligations. Figure 3 (in which the 'medium growth' scenario is assumed) shows that global production drops sharply in 1994, when the high income countries are obliged to reduce production to one-quarter of 1989 levels; by 1996, developed countries' production[19] is zero, and all remaining production is due to developing countries. This comes under Protocol control in 2005, when production must fall to 50% of 2002 levels. All production is banned by the year 2010. CFC production under the terms of the Protocol is shown in figure 4, grouped by income quintiles. The highest income quintile would have produced, in the absence of the Montreal Protocol, approximately 10 million tons of CFC 11 and 12 in the year 2000; under the Protocol, its production is required to be zero. By roughly 2020, Protocol obligation and unilateral management coincide for the richest countries.

Insert Figure 3 Obligations under the Montreal Protocol, 1990-2050

Insert Figure 4 Distribution of Obligations under the Montreal Protocol, 1990-2050

In contrast, the poorest countries (the lowest income quintile), unregulated in the year 2000, would have produced about 20 million tons of CFCs in 2020, compared to the zero production level required under the Protocol, and their production would have continued to expand through the end of the simulation (i.e. 2050). This is a clear indication that the burden of the Protocol falls almost entirely on the poorest countries.

Therefore, the comparison of these figures demonstrates that the Montreal Protocol has a pronounced aggregate and distributive impact. The difference in aggregate impact is the difference between the areas under Figure 1 (CFC production under unilateral management) and that under Figure 3 (CFC production under the Protocol). The distributive impact is evidenced by the difference between the production by the various income groupings in Figures 2 and 4. Clearly, the Montreal Protocol as designed has a substantial effect, and this is attributable primarily to the additional abatement required of the poorest countries.[20]

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[19] To be precise, 'non-article 5 countries', defined as those countries with high national incomes **or** CFC production per capita in excess of 0.3 kg of ODP.

[20] Two notes. First, it is important to acknowledge that the obligations under the Montreal Protocol and reality are two different things; however, the issue addressed here is whether joint management under the Protocol (as designed) confers additional responsibilities over those that would be adopted unilaterally, and upon whom these responsibilities are conferred. Second, it is important to acknowledge the implicit ethical assumption here that those countries developing after 1989 have the same rights to CFC-based development as those developing between 1970 and 1989. This is debatable as there is a different information base available to these later countries, and they are less likely to have sunk investments without that information. However, the response to this

5. Valuing the Incidence of an International Agreement - Technological Change

This section estimates production value losses occasioned by the Montreal Protocol. The figures are discounted sums of flows of values over the forecast period, in 1986 US$. The calculations have been performed for various combinations of the model parameters: income and price growth rates, and the discount rate. Naturally, the absolute values of the losses involved change with the different parameter values. But the distribution of losses between countries (grouped by income quintiles) has the same qualitative features in many of the scenarios.

Table 5 gives production value losses for each of the five income quintiles as well as the total losses (at mid-range assumptions). Note that the greatest losses are being experienced by the poorest countries, and that these losses are highly sensitive to the discount rate assumptions imposed. These observations illustrate that the Montreal Protocol is being financed by the elimination of development opportunities in the distant future - for the poorest of the world's countries.

***Table5.* Estimated Production Value Lost Due to Montreal Protocol (millions 1988 US$)**

Development Status of Country (Income Quintile)	CFC Growth Path Assumption	Production Value Lost: Discounted @1%	Discounted @ 5%	Discounted @ 10%
Lowest	0%	1,540	347	85
	2.5%	5,644	1,029	194
	5%	31,210	4,537	611
Second	0%	362	81	19
	2.5%	1,289	238	44
	5%	6,814	1,008	138
Third	0%	49	18	7
	2.5%	124	35	11
	5%	471	95	22
Fourth	0%	373	134	54
	2.5%	1,012	275	89
	5%	4,594	846	182
Highest	0%	5	2	1
	2.5%	11	4	1
	5%	24	8	3
Total	2.5%	8,067	1,581	339

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contention is the same as that to the first point – the only issue here is whether countries are being assigned responsibilities in excess of those that countries undertook unilaterally in the period 1975-1988.

Table 5 gives the discounted present value of producer surplus changes over the forecast period for three different real price growth rates (constant real price, 2.5% per annum and 5% per annum price growth) and three different discount rates (1%, 5% and 10%).

The real price variation is required under the analysis of technical change, indicating that the relative flows of costs and of benefits might be affected by this process. If technical change occurs, then it is possible that the balance between environmental capital flows and productive capital flows might be altered from that existing in the study period (1976-1989), in which case a new rate of benefit acquisition must be applied to the loss of CFCs. To register this possibility, we provide for three rates of benefit increases from CFCs (over 1986 levels), represented by the three rates of real price increases.

The discount rate assumption concerns the general rate of growth and change within the state's economy, and the capacity for these changes to substitute or ameliorate for the impact of ozone depletion. If there is a high rate of growth in the current economy (or expected over the 50 year time horizon) then the higher rates of discount apply.

There are two clear implications from this case study.

First, technological change (under the principle of development-based reciprocity) does not reduce the level of current compensation required for latecomers. Technological change (especially if it is environment-saving) does not remove the developing country's right to its share of the global resource, but only makes it less costly (to that country) to access its share. This means that, contrary to arguments made elsewhere, technological change increases the cost of compensating latecomers to the use of an environmental resource such as the global atmosphere.

Secondly, expected growth in developing countries is the reason that latecomers lose out. If agreements are made early enough and countries are compensated far in advance, then expected growth renders the lost options relatively inconsequential. The discount rate applied to huge physical losses fifty years out renders them manageable numbers.

This is again illustrated by the Montreal Protocol case study. Under Article 10 of the Montreal Protocol a Multilateral Fund was established. This fund has been created for the purpose of funding the "incremental cost" of substituting new technologies for ozone-depleting ones in developing country member states. The Fund was initiated with $240 million in 1991 and then replenished with $500 million in 1994 (to cover the three years through 1997), and recently renewed in the amount of another $1.0billion. Therefore, developing countries are able to receive some financial assistance in their transition from ozone depleting substances to others. Note that present value of the aggregate losses being imposed are not far off the amounts being transferred via the Multilateral Fund for the implementation of the Montreal Protocol. Hence it is at least possible that the foregone development opportunities of developing countries are being purchased at approximately their present value, precisely because they are being purchased so far in advance. In this instance, the latecomers do not appear to be losing out disproportionately.

6. Conclusions

We have attempted to develop an objective approach to assessing the incidence of an international environmental agreement. This is complicated by the fact that every state is different in the fundamental fact of its different standing in the development process. We have argued that, if development is conceived as a process in which states balance portfolios of natural and productive capital stocks, then it is possible to use the first-developing countries conduct as an indicator of the baseline that might be applied to latecomers. Giving latecomers the same right to the same resources as the first-developers is what we termed “development-based reciprocity”.

We demonstrated the application of this principle in the context of the Montreal Protocol. This paper has examined the relationship between countries’ propensity to produce CFCs and income per capita in the period before the adoption of the Montreal Protocol but after the identification of the ozone-depleting capacity of CFCs (i.e. 1975-1988). In this way we have been able to ascertain the relationship between income generation and ozone depletion, in those states first considering how to manage for this trade-off. In doing so it has applied more powerful econometric techniques than previous studies of environmental Kuznets curves. This proved particularly useful for estimating production income and price elasticities. Regression analysis estimated the turning point in the “inverted U” relationship between income and CFC use occurs around US$16,000 for production (depending on the model estimated). The income elasticity of production is approximately 3.1 (short-run) and 4.4 (long-run), while the price elasticity is 0.3 and 0.5 in the short- and long-run, respectively.

We used these results as a baseline for assessing the incidence of the Montreal Protocol. There is clear evidence that the Protocol imposes the largest production losses on the poorest countries—many (poorer) countries, which are signatories to the Protocol, will suffer significant losses from their participation. This is because their incomes are far below the unilateral management-based turning point of $16,000 per capita, and their population levels are relatively high. It is the impact of the Protocol on the future production possibilities of these – the poorest of all countries – which gives it its effectiveness.

We also calculated the value of these losses under various assumptions concerning technological change and economic growth. These were found to be in the region of $1-32 billion, depending upon the assumptions used. We found that the arguments concerning technological change did not cut against the compensation of developing countries, but in fact made their foregone rights to resources more valuable. However, the critical factor determining the value of these physical values was the passage of time and the anticipated growth in the latecomers’ economies. If compensation is paid far enough in advance, the amounts are reduced dramatically (5-3billion). These figures are not far off the aggregate values currently being used to compensate countries for foregoing the use of CFCs.

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Appendix A

Data set 1: CFC Production

Lengthy time series production data exist only for CFCs 11 and 12; this is not a serious limitation, since these two chemicals account for approximately 78% of CFC use in 1988. The data problems outlined in section 2 mean that country-level CFC production figures must be estimated by using several proxies.

There are three major steps:

1. Global production of CFC 11 and 12 (taken from AFEAS (1995)) is allocated to countries using countries' share in world production of the related chemicals polyvinyl chloride (PVC) and trichloroethylene (TCE), both chlorinated hydrocarbons.[21] PVC and TCE production figures are taken from the United Nations Industrial Commodity Yearbook;
2. Countries' income and populations are obtained from the Penn Mark V.6 World Tables (see Summers and Heston (1991));
3. U.S. CFC prices are taken from Chemical Marketing Reporter; country CFC prices are calculated by deflating using country- and year-specific price deflators taken from the Penn World tables.[22]

These calculations have been checked against U.S. production figures, which can be obtained directly from the International Trade Commission (ITC). They have also been checked against 1986 production figures reported to UNEP. Both checks show that the production estimates are reasonable.

The period of the study is truncated at 1976 due to changes in trade classifications that make it impossible to get sufficiently disaggregated data prior to that date. In any event, the analysis would have to start no earlier than 1974, since this is the year in which scientific results first suggested a link between CFCs and ozone depletion. The end year of 1988 coincides with the start of the Montreal Protocol obligations. Full data can be obtained only for 29 countries, which are listed in Table 4 above.

Appendix B

List of Figures

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[21] The best proxy for this purpose would be countries' shares in world production of carbon tetrachloride, 90\% of which is used in the manufacture of CFCs. Unfortunately, these data are not collected, and only figures on PVC and TCE are available.

[22] Strictly speaking, transportation costs from exporting to importing countries should also be included in this calculation. These can be significant for CFCs, since pressurised containers must be used, particularly for CFC 12. Prices were not adjusted for costs, since this factor should be captured in the country-specific dummies of the panel estimation (provided transportation costs have stayed roughly constant over time).