

Fostering environment efficiency through transnational linkages? Trajectories of CO₂ and SO₂, 1980–2000

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Abstract. Recent optimism about sustainability has centred on the opportunities for improvements in environment efficiency through the international diffusion of environmentally beneficial innovations. This paper investigates two claims about the conditions under which countries are most likely to realise these gains. First, 'dirtier' economies should improve their environment efficiency faster as they adopt environmentally sound technologies and policies similar to those in 'cleaner' countries, resulting in catch-up and convergence over time. Second, transnational linkages accelerate the international spread of environmentally beneficial innovations and, therefore, improvements in environment efficiency. To test these claims, we use econometric techniques to examine the dynamics and determinants of two pollutants—CO₂ and SO₂—using a panel comprising up to 114 countries over the period 1980–2000. Our empirical findings broadly support both claims. Applying tests of unconditional convergence, we find robust evidence for convergence in levels of CO₂ and SO₂ efficiency, indicating catch-up by less pollution-efficient economies over time. Similarly, confirming claims about transnational linkages, we find that imports from more pollution-efficient countries and telecommunications connectivity are associated with faster improvements in domestic CO₂ and SO₂ efficiency. Results also suggest that inward foreign direct investment is positively associated with CO₂ efficiency. Yet we find that exports to countries with high levels of pollution efficiency have no discernable effect on domestic pollution efficiency.

1 Introduction

A central theme of ecological modernisation discourse is the idea that countries can achieve more ecologically sustainable growth by improving the environment efficiency⁽¹⁾ of production and consumption. Improvements in environment efficiency allow countries to achieve 'more from less', thereby potentially counteracting the scale effect of economic growth (WCED, 1987; Weizsäcker et al, 1998). Indeed, precisely for this reason, optimism about tackling global environmental problems such as climate change has centred on the opportunities to raise environment efficiency. Our goal in the present paper is to empirically investigate two claims about the conditions under which countries are likely to realise these gains through the diffusion of environmentally beneficial innovations.

The first is that 'dirtier' economies should be able to improve their environment efficiency faster than 'cleaner' ones. Specifically, through the international transfer and adoption of environmentally sound technologies (ESTs)⁽²⁾ and policies, less pollution-efficient countries are well placed to catch up in terms of environment efficiency with their more pollution-efficient counterparts (Mielnik and Goldemberg, 2000). We should, in other words, expect cross-national convergence in pollution efficiency over time.⁽³⁾

⁽¹⁾ We define environment efficiency as economic output produced/consumed for any given use of the environment as a source or sink.

⁽²⁾ We define ESTs as any technological innovation which reduces the pollution intensity of economic activity, including: end-of-pipe technologies, clean process technologies, and/or less pollution-intensive energy types.

⁽³⁾ We use the terms environment efficiency, emissions efficiency, and pollution efficiency interchangeably throughout the text.

A second claim is that a country's environment efficiency will be influenced by its connections with other countries, with transnational linkages accelerating improvements in domestic pollution efficiency. Such suggestions have typically been made in relation to trade and investment linkages, which are said to increase the supply and demand for ESTs (OECD, 1998; Wallace, 1996). More recently, however, similar arguments have been made about the spread of environmental policy innovations (Garcia-Johnson, 2000; Rock, 2002; Vogel, 2000).

Unfortunately, existing empirical work has done a poor job of empirically scrutinising either of these claims. Therefore, with a view to advancing current understanding, the present paper uses large sample, econometric estimation techniques to examine whether: (1) there is evidence of less environment-efficient countries catching up with more pollution-efficient ones, that is, convergence over time; and (2) countries' transnational linkages—via trade, investment, and telecommunications—influence the rate at which they improve domestic pollution efficiency.

Our study is an advance on previous empirical work in four important ways. First, our sample includes a far larger number of countries (up to 114), comprising the majority of the world's economies and capturing nearly 90% of the global population (see appendix B). By contrast, past work has typically focused on a subset of developed and/or developing countries, and therefore potentially suffers from selection bias (Hilton, 2001; IEA, 1994; Markandya et al, 2006; Mielnik and Goldemberg, 2000). Second, we deploy more sophisticated measures to examine the influence of a country's trading partners on domestic environment efficiency. Invariably, past studies have taken general trade flows and/or openness to capture efficiency-enhancing spillover effects, ignoring differences in environment efficiency in trading partners (Reppel-Hill, 1999). In contrast, we use both import and export variables that account for levels of pollution efficiency in countries with which a particular economy is linked via trade, and restrict our focus to goods that are likely to strongly influence domestic pollution efficiency. Third, we go beyond existing studies in our conceptualisation of transnational linkages. As well as trade and investment, our study considers the influence of a country's transnational telecommunications connectivity. The importance of international communications has begun to receive growing recognition in the literature on technological diffusion (Gong and Keller, 2003; Wong, 2004) and cross-border investment flows (Portes and Rey, 2005). Uniquely, our study investigates their role in catalysing improvements in pollution efficiency.

Fourth, we focus on two pollutants, carbon dioxide (CO₂) and sulphur dioxide (SO₂). The norm for past studies is one pollutant (Hilton, 2001; Mielnik and Goldemberg, 2000). We selected these pollutants since they are key sources of environmental damage and, therefore, indicators of the extent to which countries have decoupled economy from environment. CO₂ is the leading contributor to anthropogenic global warming; SO₂ is a major cause of ecosystem acidification (but, as explained later, also potentially counteracts the radiative effect of CO₂). Another reason for selecting these pollutants is that data exist on national emissions of CO₂ and SO₂, for a large number of countries and years, whereas for other pollutants no such data with wide country and temporal coverage exist.

We also concentrate on both CO₂ and SO₂ since they differ across a number of important dimensions. SO₂ is a characteristic 'first-generation' pollutant (Graham, 1999), in that a large share of emissions derive from point sources, are comparatively cheap to abate through end-of-pipe technologies, and involve potentially costly, short-term impacts. Conversely, CO₂ is a stereotypical 'second-generation' environmental problem. Emissions originate from a large number of diffuse sources, are potentially difficult and costly to abate, and involve impacts that are geographically and temporally dispersed.

Important differences also exist in the incentives to abate CO₂ and SO₂. First, the gases differ in the relative importance of market versus regulatory drivers. The impetus to cut CO₂ has historically derived almost exclusively from nonenvironmental market pressures and, specifically, the drive to reduce energy costs amongst producers and/or consumers. Market-driven technological change has similarly played an important role in reducing SO₂ emissions through process-integrated improvements. However, because abating sulphur does not always contribute to improved competitiveness, environmental regulations have also assumed considerable significance in compelling firms to reduce SO₂ emissions—either through investments in end-of-pipe equipment, ‘clean’ process technologies, and/or switching to less sulphur-intensive fuels (Popp, 2006; Taylor et al, 2005).

Furthermore, the incentive to ‘free ride’ off other countries’ domestic abatement efforts differs. SO₂ is a regional (transboundary) pollutant, characterised by an asymmetric problem structure. That is, the environmental impacts experienced by a particular country from SO₂ emissions are not equal, but vary according to its own emissions and those of its geographically proximate neighbours (Murdoch and Sandler, 1997; Sandler and Sargent, 1995). Conversely, CO₂ is a truly global (transboundary) pollutant, characterised by greater symmetry amongst countries. Although predicted to vary, with developing countries bearing a disproportionate burden, few countries are likely to escape the longer term negative environmental consequences arising from CO₂ emissions (IPCC, 2007). In principle, to the extent that emission reductions are a public good, there are incentives for countries to free ride off cuts in both CO₂ and SO₂ emissions made by other states. Yet, as discussed below, the regional and asymmetrical characteristics of SO₂ suggest that domestic abatement effort is likely to be far more strongly influenced by the actions of geographical neighbours.

The rest of the paper is structured as follows. Section 2 explores the conceptual foundations for convergence in pollution efficiency. Section 3 discusses claims about the role of international trade, investment, and telecommunications connectivity in accelerating improvements in environment efficiency. Section 4 outlines the findings of past empirical work. Section 5 details our research design while results are presented in section 6. Finally, in section 7 we discuss the wider implications of our findings.

2 Conceptualising convergence in environment efficiency

Why should we expect catch-up and, by implication, convergence in environment efficiency? According to the literature, there are two possible mechanisms. The first involves the international spread of technology (Mielnik and Goldemberg, 2002). Technology is widely recognised as a central determinant of the pollution intensity of a country’s consumption and production activities (Weizsäcker et al, 1998). Technological progress means that many modern technologies used in (potentially) energy-intensive and/or resource-intensive applications are often considerably less environment intensive than their older counterparts. As these designs and configurations diffuse—that is, spill over—from more to less technologically advanced countries, and the installed technological base becomes more similar among those countries, so it follows that the pollution efficiencies of national economies should converge.

Indeed, international technological spillovers—embodied in physical equipment and disembodied as technological know-how—have long been theorised as a central mechanism in economic models of convergence, which predict catch-up in income levels over time (Gong and Keller, 2003). Central to this hypothesised process of catch-up is the existence of transnational networks connecting geographically dispersed countries. Through transnational linkages, countries can take advantage

of technologies developed in more advanced economies, allowing indigenous firms to leapfrog decades of potentially costly technological effort (Wong, 2004). In addition, transnational linkages are hypothesised to transmit price effects, with less efficient firms investing in more modern, productive technologies in order to compete in product markets with high-efficiency foreign competitors.

Similar arguments have been advanced in relation to environmental performance and efficiency. Engagement with other countries via transnational networks is said to expand the domestic availability of ESTs, as well as to enhance the demand for more modern, efficient technologies (Grubb et al, 2002; Reppelin-Hill, 1999; Rock, 2002; Warhurst and Bridge, 1997). Pollution-inefficient countries should therefore catch up as they invest in environment-efficient technologies similar to those deployed in more environment-efficient economies. Typically, such claims have been made for developing countries, although they are equally relevant to lagging, environment-inefficient developed ones (Markandya et al, 2006).

Whether developed or developing, however, as countries approach the technological frontier, so their ability to secure further improvements in pollution efficiency will inevitably decline. The latest technologies do not benefit from learning investments. They are, therefore, frequently more costly, unreliable, and risky, characteristics which reduce their uptake by potential adopters. The result: the rate of catch-up should decline as countries improve their pollution efficiency over time.

A second mechanism of catch-up centres on the geographic spread of similar policy ideas, instruments, and regulatory approaches (Tews et al, 2003). This may involve nonenvironmental policy developments with positive environmental consequences (Grubb et al, 2002). More directly, convergence may arise from the spread of environmental policies, which compel actors in different countries to achieve similar environmental performances (Hilton, 2001). Hence, countries can sign up to regional and/or global treaties, obligating signatories to comply with restrictions governing their environmental behaviour (Tews et al, 2003). Alternatively, policies may diffuse horizontally, spreading from high-regulating states to low-regulating ones. Indeed, there is anecdotal evidence that, following the lead of developed countries, a growing number of developing ones are now adopting standards governing SO₂ (Couch, 1999; Rock, 2002).

Of course, cross-national convergence in environment efficiency does not necessarily imply ecologically 'sustainable' outcomes. What ultimately matters for sustainability is the extent to which improvements in environment efficiency (ie 'technique') offset the effects of continued economic growth (ie 'scale'). For CO₂, models suggest that economic growth is likely to lead to rapidly rising emissions over the coming century, with potentially catastrophic consequences for climate stability (IPCC, 2007). It is beyond the scope of the present study to empirically investigate the net outcome of scale and technique effects. We simply note here that convergence in environment efficiency might be expected to slow the rate of CO₂ emissions growth. In the case of SO₂, convergence may also slow emissions growth in some countries and accelerate reductions in others. Paradoxically, however, this may aggravate anthropogenic warming, in that sulphate aerosols are believed to have an indirect cooling effect.

3 The role of transnational linkages

A unifying feature of the above accounts is the functional importance ascribed to various transnational linkages. Foremost amongst these linkages identified in the existing literature are international trade and investment (OECD, 1998). In the next two sub-sections, we examine their hypothesised role in improving environment efficiency, before going on to consider other possible transnational linkages.

3.1 Trade

The argument that international trade creates favourable conditions for raising environment efficiency rests chiefly on its role in accelerating the diffusion of ESTs. Directly, imports allow domestic actors to acquire new and/or cheaper ESTs, and indirectly, may increase the supply of new technology via knowledge spillovers. Exports may also engender knowledge spillovers as indigenous firms learn from foreign competitors about ways to improve process and/or product technologies in the direction of greater environment efficiency (Chuang, 2002). Further, by exposing indigenous firms to greater competition, trade flows potentially provide an impetus for investments in modern, efficient technologies with higher levels of embodied environmental performance (OECD, 1998).

Import and export linkages are additionally thought to accelerate the diffusion of environmental policies from high-regulating states to low-regulating ones (Vogel, 2000). Trade ties facilitate cross-border learning about the existence, benefits, and legitimacy of environmental policy interventions, providing the foundations for emulative dynamics. They also expose countries to enhanced international scrutiny regarding their domestic environmental performance and, possibly, coercive environmental pressures from more powerful trading partners (Falkner, 2006; Frank et al, 2000; Tews et al, 2003; Vogel, 2000). In doing so, it is suggested that imports and exports potentially foster 'upwards' environmental policy convergence amongst trading partners.

Yet the positive contribution of trade is unlikely to be automatic. In reality, there are two factors that might be expected to determine the extent to which trade ties influence domestic environment efficiency (Chuang, 2002). The first is the identity of the trading partner. Import and export ties with economies characterised by high levels of environment efficiency are more likely to lead to improvements in domestic pollution efficiency (cf Coe et al, 1997; Wong, 2004). Another factor determining the environmental impact of trade is the nature of the traded good, with certain imports/exports likely to have a far greater potential influence on environment efficiency. Included here are (i) capital goods involved in the production of potentially pollution-intensive goods, and (ii) intermediate and/or final goods whose production and/or consumption is potentially pollution intensive.

3.2 Investment

A second transnational economic linkage widely theorised to accelerate the cross-national transfer and diffusion of ESTs is foreign direct investment (FDI). As generators, owners, and users of many of the world's most advanced technologies, transnational corporations (TNCs) are assumed to play a lead role in efficiency-enhancing investments (Mielnik and Goldemberg, 2002). TNCs may introduce more modern ESTs to host economies directly through investments in subsidiaries, joint ventures, and affiliates, or through the sale of their proprietary technologies to domestic consumers and producers (OECD, 1998). Additionally, FDI may generate environmentally beneficial technological spillovers, as well as raise environment efficiency through competitive dynamics. Furthermore, it is suggested that 'green' procurement requirements imposed by TNCs on domestic suppliers may create supply-chain pressures for the adoption of beyond-compliance (voluntary) environmental codes, standards, and management practices (Neumayer and Perkins, 2003).

Again, the impact of each unit of inward investment is unlikely to be homogenous. Thus, investments in environment-intensive sectors of the economy should plausibly have a far greater impact on domestic pollution efficiency than those made in comparatively unpolluting economic sectors. Compared with imports, however, the identity

of the foreign investor is likely to be less pivotal. The majority of FDI originates in developed economies, where levels of technical efficiency and regulatory standards are generally comparatively high. Hence it follows that FDI should, by and large, embody positive environmental spillovers.

3.3 Communications

While much of the literature on environmental convergence has defined transnational linkages narrowly in terms of trade and investment, this conception is at odds with the mainstream literature on globalisation. This emphasises the myriad of economic, political, and social–cultural linkages that comprise globalisation and, moreover, their role in shaping distanced geographies (Murray, 2006). In the present paper we focus on one such transnational linkage that has received growing attention: international telecommunications (Gong and Keller, 2003; Portes and Rey, 2005; Wong, 2004).

The most obvious way in which international telecommunications linkages could accelerate the diffusion of ESTs—and therefore ‘upwards’ convergence in environment efficiency—is by facilitating cross-border learning about the availability, cost, and performance of new technologies. Through telephone calls and web surfing, firms might come to learn about potentially profitable ESTs. Indeed, to the extent that information is a major impediment to the adoption of ESTs, telecommunications linkages are likely to accelerate their geographic spread. Telecommunications could also facilitate the flow of disembodied technical knowledge (Wong, 2004). Telephone calls with foreign customers, consultants, and competitors may provide domestic firms with new ideas about how to improve, for example, the energy efficiency of their production processes.

At a more general level, remote communications with other countries might foster the domestic internalisation of global norms of environmentalism. As citizens come to learn about environmentalism in other countries, so they may become socialised into accepting environmental protection as a legitimate goal (Frank et al, 2000). International communications flows might also support domestic learning about external environmental regulatory developments, raising domestic expectations regarding the ‘appropriate’ level of environmental policy (Falkner, 2006). Transnational benchmarking of this sort has frequently been deployed by environmental nongovernmental organisations in lobbying governments for more stringent environmental policy (Mason, 2005). However, similar processes are also likely to operate amongst the wider public as they learn via communications from their overseas peers about stronger levels of environmental commitment and create political demand for similar environmental policies.

Of course, implicit in the above discussion is the idea that it is not only the volume of transnational traffic that should matter, but also with whom a country communicates. It follows that communications with highly pollution-efficient countries are likely to have a positive impact on domestic pollution efficiency, as actors learn from and, moreover, emulate their environmentally progressive peers. Conversely, communicating with actors in countries characterised by low levels of pollution efficiency is unlikely to spill over into improved levels of domestic pollution efficiency, although neither is it likely to retard efficiency gains.

4 Existing research: emissions, technology, and regulation

Previous empirical studies have provided only partial support for each of the above claims. On the question of catch-up, a number of authors have found evidence for cross-national convergence in energy intensity (IEA, 1994; Lindmark, 2004; Markandya et al, 2006; Mielnik and Goldemberg, 2000). Along similar lines, Hilton (2001) found evidence that late industrialising (ie developing) countries adopt environmental policy

measures at lower levels of income than industrialised (ie developed) economies did in the past. Yet none of these studies directly examine catch-up and convergence in pollution efficiency or derive their results from a large sample both of developed and of developing countries.

Likewise, evidence linking trade and investment to improved pollution efficiency is limited. Several studies generally show that countries which are more open to trade diffuse modern technologies more rapidly (Gruber, 1998; Perkins and Neumayer, 2005; Reppelin-Hill, 1999), although these works fail to explore the implications for countries' environment efficiency. Conversely, systematic evidence linking FDI with the more rapid adoption of ESTs is sparse, with the majority of studies finding little or no effect from the presence of TNCs (Andonova, 2003; Perkins and Neumayer, 2005). More directly, Mielnik and Goldemberg (2002) found that countries with higher levels of FDI have reduced their energy intensity faster, albeit they used a bivariate correlation without control variables and a sample of only twenty states.

A number of studies have found that transnational linkages via trade and investment have been associated with the adoption of new and/or more stringent government regulatory policies (Garcia-Johnson, 2000) and private regulatory codes (Neumayer and Perkins, 2003). Yet, in stark contrast to trade and investment, the role of telecommunications in accelerating the diffusion of ESTs and environmental policies has been neglected in the existing literature. Wong (2004) found evidence that telephone calls with more productive countries increase domestic levels of productivity; and we have found (Neumayer and Perkins, 2005) that countries with a higher density of telephones have more ISO 9000 certificates—a productivity-enhancing quality-management system standard. To our knowledge, however, no quantitative studies have examined the role of telecommunications specifically in relation to ESTs, policies, or environment efficiency.

With a view to providing a more relevant, generalisable, and robust test of claims about convergence and transnational linkages, in the present study we use data on CO₂ and SO₂ efficiency for up to 114 countries over the period 1980–2000. We adopt a two-staged analytical approach. In the first, we apply a β -convergence cross-sectional regression model; in the second we use a fixed-effects regression model to estimate the role of trade, investment, and telecommunications linkages. Further details about our research design are provided in the next section.

5 Research design

5.1 Estimation strategy

We begin our empirical investigation by analysing what the economic literature on income convergence terms 'absolute' or 'unconditional' convergence (eg see Barro and Sala-i-Martin, 2004; Islam, 2003). Countries are said to be absolutely or unconditionally converging in a variable y if, over a longer span of time, and without conditioning on a set of other explanatory variables, countries with higher initial levels of y experience slower growth in y than do countries with lower initial levels of y . Formally, one can test for unconditional convergence by estimating the following regression equation:

$$\text{growth in } y \text{ over total period} = \alpha + \beta \ln(\text{initial level of } y) + u.$$

This test is commonly known as ' β -convergence'. A negative β that is statistically significantly different from zero would indicate convergence. We also briefly report the change in the standard deviation of the natural logs of pollution efficiency. Also known as ' σ -convergence', this measures the spread of the distribution of a variable.

In order to analyse the impact of transnational linkages on the rate of change in countries' pollution efficiency, we switch from a simple cross-sectional analysis to a panel-data model, which allows us to control for country fixed effects. Formally, we use the following model, in which i stands for country, and t for time:

$$\ln y_{it} - \ln y_{it-1} = \alpha + \beta_1 x_{it} + \beta_2 \ln y_{it-1} + a_i F_i + \text{year}_t + u_{it}, \quad (1)$$

where $\ln y_{it} - \ln y_{it-1}$ is growth in pollution efficiency, or, equivalently,

$$\ln y_{it} = \alpha + \beta_1 x_{it} + (\beta_2 + 1) \ln y_{it-1} + a_i F_i + \text{year}_t + u_{it}. \quad (2)$$

In practice, we estimate equation (2). The dependent variable is thus pollution efficiency, that is, GDP divided by emissions. The x_{it} contain our explanatory transnational linkage variables, described below, as well as control variables. Lagged pollution efficiency is included as a further control variable. One would expect countries with lower levels of pollution efficiency to improve their efficiency faster than countries with higher levels of pollution efficiency. This should carry over into conditional convergence, where 'conditional' means that other explanatory variables are included. The F_i contain $N - 1$ country dummy variables. Their inclusion is important because country-specific factors that are invariant over time—or close to invariant—could possibly impact on pollution efficiency and be correlated with our explanatory variables. If not controlled for, this would bias our results. The year-specific dummy variables year_t capture general global trends in emissions efficiency over time. The u_{it} is a stochastic error term.

We estimate the model with Arellano and Bond's (1991) dynamic generalised method of moments (GMM) instrumental variables estimator with robust standard errors. This estimator works by first-differencing equation (2), which eliminates the F_i fixed effects, and by using past levels of the lagged dependent variable, along with the endogenous variables lagged by two or more periods, as instruments. First-order autocorrelation in the original data is unproblematic, but the estimator depends on the assumption of no second-order autocorrelation in the first-differenced idiosyncratic errors. This assumption was tested, and the test results fail to reject it (see below). The Arellano and Bond estimator has the important advantage that the spatial lag variables can be explicitly specified as endogenous, that is, their past and contemporaneous values are allowed to be correlated with the error terms.

5.2 Dependent variables

Our dependent variables are growth over the entire period 1980–2000 in emissions efficiency of CO₂ and SO₂, that is, the growth in GDP per unit of CO₂ and SO₂ for the cross-sectional convergence analysis. For the panel-data analysis, the dependent variable is pollution efficiency. Data on CO₂ emissions and GDP per capita in purchasing-power parity (PPP) were taken from IEA (2005), and data on SO₂ emissions from Stern (no date). We use GDP on a PPP basis rather than the more conventional GDP at exchange rates, since the latter is well known to understate the purchasing power of currencies in low-income economies. We distinguish developing countries (from the full sample) in our convergence analysis and econometric estimations using standard World Bank country classifications. Appendix A provides summary descriptive statistics for all variables.

5.3 Key explanatory variables

To capture the influence of trade linkages, we focus on the spillover effect of ESTs, policies, and levels of environment efficiency in countries with which a particular economy is linked through imports and exports of (potentially) polluting goods. Our specific variables are the lagged emissions efficiency of trading partners from which a particular economy imports and to which it exports its machinery and manufactured

goods, weighted by the relative import/export share of the trading partner in the domestic country's total machinery and manufactured-goods imports/exports.⁽⁴⁾ In essence, our measures comprise a spatial lag or spatial autoregressive model, which has recently become popular among social scientists investigating the international diffusion of technological, regulatory, and organisational innovations (eg see Beck et al, 2006; Perkins and Neumayer, 2004; Simmons and Elkins, 2004). In the present paper the pollution efficiencies of countries are linked with each other—in effect, allowing environment efficiency in one country to spill over into another—via a transformation mechanism represented by a connectivity matrix. In our case the matrix is given by bilateral machinery and manufactured goods import and export shares, with data taken from UN (2006). Owing to the high correlation coefficients between the two trade measures (0.55 and 0.73 for CO₂ and SO₂, respectively), we include the import measure, for which we have a stronger theoretical expectation, once on its own before including both imports and exports together in a separate estimation.

The rationale for our particular trade measures is twofold. First, we want to measure only the efficiency spillover effect associated with imports and exports that might have a substantive influence on domestic CO₂ and SO₂ efficiency. Manufactured goods are important in this respect since their production is often comparatively environment-intensive. Increased price and/or quality competition—either from imports, or foreign competition in export markets—might bring about improvements in domestic environment efficiency as indigenous firms invest in more modern, efficient production (and/or product) technologies. The importance of manufactured goods—and particularly imported ones—also potentially derives from their in-use performance. To take one example: products such as cars imported from more environment-efficient economies should have a positive impact on domestic environment efficiency. The same goes for foreign capital goods embodying high levels of environmental performance. Indirectly, imports of machinery may also lead to efficiency-enhancing knowledge spillovers, as indigenous firms appropriate foreign knowledge required to acquire, implement, and possibly produce ESTs (Coe et al, 1997). Exporters of machinery might similarly engage in learning, although the case for knowledge spillovers via imports is stronger.

A second reason for our distinctive trade measures is the need to discriminate between levels of technology and/or environment-relevant policies in the partner country. A low level of pollution efficiency is likely to indicate a more environment-inefficient technological base, lax environmental standards, and/or policies that indirectly encourage pollution. Hence import and export linkages with such countries are unlikely to bring about significant improvements in domestic pollution efficiency. Conversely, machinery and manufactured goods imports from and, to a lesser extent, exports to, pollution-efficient economies are more likely to generate positive environmental spillovers, particularly via price effects and embodied technical efficiency.

Unfortunately, we cannot apply a similarly sophisticated measure for FDI. Comprehensive data exist for neither bilateral flows nor the sectoral allocation of FDI—at least for a large sample of countries. In their absence, we fall back on a simple aggregate measure, namely, cumulative stock of inward FDI relative to GDP (data taken from UNCTAD, 2004). We measure the influence of FDI using the stock, rather than volatile annual FDI inflows.

⁽⁴⁾ The lagged foreign emissions efficiency is used because estimating a model using its contemporaneous value renders model estimation extremely difficult, given that countries would affect and be affected by other countries' emissions efficiency simultaneously (Beck et al, 2006). Even conceptually, it makes more sense to use the lag because machinery and manufacturing imports are likely to embody the lagged, rather than contemporaneous, emissions efficiency of the exporting country.

Our third explanatory variable is a measure of telecommunications connectivity. As with FDI, a lack of comprehensive bilateral data on telephone calls and Internet traffic means that it is not possible to construct a spatial lag variable. Instead, we measure a country's telecommunications linkages using the first principal component of two variables: the number of internet users per capita, and international outgoing telephone traffic (in minutes) per capita⁽⁵⁾—data from the World Bank (2005) and the International Telecommunications Union (ITU, 2003). While our measure does not account for differences in the pollution efficiency of economies with which a particular country communicates, it seems implausible that telecommunications flows should involve negative environmental spillovers.

5.4 Control variables

As well as our main explanatory variables, we specify two general control variables both for CO₂ and for SO₂, as well as a further set of specific control variables for SO₂. The first general control variable is GDP per capita in PPP (data from IEA, 2005). We include per capita income as a proxy for several features of a country's economy, politics, and society which might plausibly shape domestic environmental quality. These include popular demand for environmental protection, as well as the ability of governments to meet this demand through the enactment and enforcement of environmental policy, both of which are likely to grow as countries become richer (Grossman and Krueger, 1995). They also include the capabilities of firms to purchase, implement, and operate capital-intensive ESTs (Lall, 1992). Although we would have ideally preferred to capture such dynamics directly, appropriate proxies with sufficient spatial and temporal coverage simply do not exist. Yet we believe that per capita income is sufficiently correlated with these dynamics that its inclusion reduces potential omitted-variable bias (eg see Dasgupta et al, 2001).

Our second general control variable is the share of industry in total value added. Industry—mining, manufacturing, construction, electricity, water, and gas—is a leading source of CO₂ and SO₂ emissions. All things being equal, a more industry-intensive economy will have a lower CO₂ and SO₂ efficiency. Hence we seek to control for the contribution of industry in order to ensure that our estimations do not simply pick up a (potentially misleading) structural effect, that is, shifts in the composition of the economy over time.

For SO₂, we include two further sets of control variables in separate estimations. First, we control for the potential effect of multilateral environmental agreements on SO₂ emissions efficiency during our period of study.⁽⁶⁾ These comprise two agreements—the 1985 Helsinki Protocol and the 1994 Oslo Protocol—covering various European and Northern American states. The Helsinki Protocol required all signatories to reduce emissions by 30%, whereas the Oslo Protocol imposed differentiated obligations on parties. We include two variables measuring the natural log of the number of years since a country has signed the Helsinki or Oslo Protocols if it is a signatory, and zero otherwise, to account for the fact that the protocols should have an effect that is increasing over time, but at a decreasing rate.

Second, we control for levels of SO₂ emissions in contiguous countries. Levels of acid deposition from SO₂ in one country will be influenced by emissions in neighbouring countries, together with the location of these countries and prevailing wind patterns. An important consequence of this—combined with the potentially high costs

⁽⁵⁾ The first principal component captures 69% of variation in the variables. Owing to limited data availability, we are forced to omit incoming calls.

⁽⁶⁾ We ignore the Kyoto Protocol for CO₂ because its emission-reduction period (2008–12) is well beyond the end year of our study.

of abating sulphur—is that any one country will have an incentive to act strategically in relation to emissions from its neighbouring countries. Murdoch and Sandler (1997) theorise these dynamics in terms of an ‘acid-rain game’, whereby emission reductions in neighbouring countries generate positive externalities, inducing a country to reduce its own emissions by less than it otherwise would (assuming a convex marginal damage function). Unfortunately, formally modelling these strategic responses convincingly requires knowledge of the so-called ‘transport matrix’, which shows the percentage of country A’s emissions which is ‘exported’ into neighbouring countries and the percentage of country’s A pollution load which is ‘imported’ from other countries. To our knowledge, no such matrix exists for a global sample, and creating one is far beyond the scope of our paper. In the absence of these data, we proxy the strategic response of individual states by including the log of the average level of SO₂ emissions of contiguous countries, that is, of countries that share a common land border, or are separated by a sea distance of less than 150 miles. Although we would ideally have liked to examine these dynamics by means of a transport matrix, it is worth noting recent work by Maddison (2007) who finds little evidence for an acid-rain game in the European context, suggesting that our inability to account fully for strategic reactions is unlikely to bias the results.

6 Results

Table 1 shows tests of β -convergence over the period 1980–2000 in CO₂ and SO₂ efficiency. Period growth in efficiency is regressed on the log of initial efficiency in 1980. For both pollutants and both samples, the coefficients of the log of the emissions efficiency in 1980 are negative and statistically significantly different from zero, indicating that less pollution-efficient countries are catching up with more pollution-efficient ones. These results are confirmed by looking at σ -convergence. The full-sample standard deviations of the natural log of CO₂ and SO₂ efficiency decrease from 0.88 and 1.65 in 1980 to 0.78 and 1.43 in 2000, respectively. In the developing-countries sample, the respective decrease is from 0.95 to 0.85 for CO₂, and from 1.41 to 1.23 for SO₂.

The speed of convergence can be estimated by $\ln(\beta + 1)/T$, where T is the number of years of the study period. In the global samples, the estimated rate of convergence is around 1.9% per annum for CO₂ and approximately 3.6% per annum for SO₂ efficiency.⁽⁷⁾

Table 1. Unconditional β -convergence analysis.

	CO ₂ efficiency		SO ₂ efficiency	
	full sample	developing countries	full sample	developing countries
In emissions efficiency in 1980	−0.312 (6.86)***	−0.270 (5.58)***	−0.511 (4.48)***	−0.461 (3.68)***
Constant	0.327 (4.96)***	0.239 (2.98)***	0.354 (2.51)**	0.149 (1.26)
Number of countries	112	79	110	76
R ²	0.25	0.22	0.34	0.31

Significant at 5%; *significant at 1%.
Note. Ordinary least squares regression. Dependent variable is period growth in emissions efficiency from 1980 to 2000, with absolute robust t -statistics shown in parentheses.

⁽⁷⁾ This means that 1.9% and 3.6% of the gap between a typical environment-efficient and a typical environment-inefficient country is eliminated in one year, respectively. If maintained, this rate of convergence would imply that half of the gap is eliminated in 36 and 19 years, respectively.

These are moderate rates of convergence. However, it is interesting to note that SO₂ efficiency converges faster than CO₂ efficiency. Most likely this reflects the lower costs and/or difficulty of cutting SO₂ emissions, which can be readily abated from major point sources through end-of-pipe technologies and/or fuel switching. Additionally, it may reflect the high and tangible costs of acid deposition, and the comparatively rapid spread of SO₂ emission standards across a range of developed and developing countries during recent decades. The exclusion of developed countries from the sample does not greatly change the estimated speeds of convergence (1.6% and 3.1% per annum, respectively), indicating that our findings are not simply driven by developed economies.

We now address the more interesting question of what, besides its lagged level, determines emissions efficiency. Tables 2 and 3 show our Arellano and Bond (1991) GMM instrumental variables estimation results for CO₂ and SO₂, respectively.

With one exception, the coefficient for our import variable is positive and statistically significant in the case of both air pollutants. In other words, countries which obtain a larger share of their manufactured goods and machinery imports from economies with high levels of CO₂ and SO₂ efficiency experience faster improvements in domestic pollution efficiency for these pollutants. The result is similar for the full sample and the developing-country subsample. The only anomalous result is for SO₂, notably when the export variable is simultaneously included, which might suggest multicollinearity problems.

Yet exports do not have a similar effect on environment efficiency. Countries which send a larger share of their manufactured goods and machinery exports to economies with high levels of CO₂ and SO₂ efficiency do not improve their domestic emissions efficiency any faster. Although failing to confirm recent claims about the role of export markets

Table 2. The determinants of CO₂ efficiency.

	Full sample		Developing countries	
In emissions efficiency ($t - 1$)	0.664 (11.46)***	0.677 (12.87)***	0.642 (9.31)***	0.688 (12.19)***
Machinery and manufactured goods-import-weighted spatial lag ($t - 1$)	0.201 (2.47)**	0.120 (1.62)*	0.220 (2.64)***	0.134 (1.94)*
Machinery and manufactured goods-export-weighted spatial lag ($t - 1$)		0.025 (0.68)		0.034 (0.87)
Foreign direct investment stock	0.001 (1.90)*	0.001 (1.85)*	0.003 (3.13)***	0.001 (1.59)
Telecommunication principal component	0.011 (2.83)***	0.012 (3.37)***	0.001 (0.07)	-0.001 (0.16)
ln GDP per capita	0.291 (5.48)***	0.252 (3.04)***	0.260 (3.96)***	0.195 (3.22)***
Percentage industry value added	-0.004 (2.79)***	-0.004 (3.04)***	-0.002 (1.56)	-0.003 (2.34)*
Number of observations	1451	1409	959	918
Number of countries	114	113	85	84
Test of no second-order autocorrelation (p -value in parentheses)	0.53 (0.59)	0.64 (0.52)	0.30 (0.77)	0.21 (0.83)

*Significant at 10%; **significant at 5%; ***significant at 1%.
Note: Arellano and Bond (1991) GMM estimation. Coefficients of year-specific time dummies and constant not reported. Dependent variable ln emissions efficiency; absolute robust z -statistics are shown in parentheses.

Table 3. The determinants of SO₂ efficiency.

	Full sample		Developing countries		Full sample including protocol and contiguous-country emissions control variables	
ln emissions efficiency ($t - 1$)	0.617 (5.42)***	0.643 (6.44)***	0.474 (4.20)***	0.633 (6.49)***	0.660 (6.05)***	0.657 (7.04)***
Machinery and manufactured goods-import- weighted spatial lag ($t - 1$)	0.396 (2.87)***	0.263 (2.68)***	0.145 (1.84)*	0.090 (1.20)	0.319 (2.46)**	0.183 (2.04)**
Machinery and manufactured goods-export- weighted spatial lag ($t - 1$)		0.041 (0.97)		0.038 (1.19)		0.033 (0.76)
Foreign direct investment stock	0.001 (0.49)	0.001 (0.38)	−0.001 (0.46)	−0.001 (0.91)	−0.001 (0.02)	0.001 (0.01)
Telecommunication principal component	0.049 (2.48)**	0.043 (2.52)**	0.242 (2.57)**	0.142 (2.54)**	0.057 (2.38)**	0.042 (2.30)**
ln GDP per capita	0.268 (1.44)	0.285 (2.30)**	0.325 (2.54)**	0.341 (4.13)***	0.230 (1.16)	0.275 (0.09)
Percentage industry value added	0.008 (0.57)	0.005 (0.47)	−0.010 (3.12)***	−0.007 (2.75)***	0.003 (0.23)	0.003 (0.31)
Helsinki Protocol					0.278 (2.94)***	0.205 (2.90)***
Oslo Protocol					−0.012 (1.02)	−0.003 (0.27)
ln contiguous emissions					9.93 (2.32)**	5.02 (1.65)*
Number of observations	1448	1406	956	915	1448	1406
Number of countries	113	112	84	83	113	112
Test of no second-order autocorrelation (p -value in parentheses)	0.92 (0.36)	0.61 (0.54)	0.77 (0.44)	−0.28 (0.78)	0.80 (0.42)	0.56 (0.57)

*Significant at 10%; **significant at 5%; ***significant at 1%.

Note: Arellano and Bond (1991) GMM estimation. Coefficients of year-specific time dummies and constant not reported. Dependent variable ln emissions efficiency; absolute robust z -statistics are shown in parentheses.

in 'trading-up' (Vogel, 2000), the discrepancy might reflect the fact that the potential mechanisms by which high levels of environment efficiency in trading partners spill over into the domestic economy are more numerous and diverse in the case of imports. To take one example: while imports of advanced capital goods are likely to be a central vehicle for raising domestic environment efficiency, no equivalent mechanism exists for exports. What is more, the influence of imports on domestic environment efficiency is likely to be more widespread. Thus, efficiency-enhancing knowledge spillovers from exports are only likely to accrue to domestic exporters in the short to medium term, whereas spillovers from imports might be available to a far wider set of domestic actors.

A higher inward FDI stock is associated with higher CO₂ efficiency. In table 2, this variable is insignificant for the developing country sample, but only very marginally so ($p = 0.111$), and only in one estimation. Yet inward FDI has no effect on SO₂ efficiency. The most likely explanation for these differences between the two pollutants lies in their respective sources. As explained above, CO₂ is a more diffuse pollutant, originating from a diverse set of actors, applications, and processes. Irrespective of the sector(s), investments by TNCs are therefore likely to impact on domestic levels of CO₂ efficiency. Conversely, the majority of anthropogenic SO₂ emissions originate from a single source—electricity generation—meaning that only FDI in this sector is likely to have a substantive influence on emissions. And because investments by transnational corporations in the electricity sector have generally remained small, our finding for SO₂ is perhaps unsurprising.

Uniquely, we find evidence that international communications linkages act as a catalyst for improvements in countries' pollution efficiency. The estimated coefficient for the telecommunications-connectivity variable is positive and statistically significant throughout for SO₂ efficiency. For CO₂ efficiency, however, it is only significant in the full sample. It may be that the influence of telecommunications connectivity in developing countries operates primarily by accelerating the downloading of more stringent regulations from high-regulating states—something which is likely to have a negligible impact in the case of CO₂ given that few states had adopted emission-reduction targets similar to those for SO₂ during our period of study.

Moving to our control variables, the picture is mixed. The industry value added coefficient is statistically significant for CO₂ in both samples, with the expected negative coefficient sign (just nonsignificant in the third column, developing-country sample), but for SO₂, it is *only* significant in the developing-country sample. The coefficient for GDP per capita is significant for CO₂. Yet it is only significant with the expected positive coefficient sign for SO₂ in three of the six estimations. Of note, GDP per capita becomes clearly nonsignificant if the Helsinki and Oslo Protocol variables are added to the full sample. Only relatively rich countries have signed these protocols, so our regulatory variables are likely to pick up some of the effect of the wealth differential among countries, rendering the GDP per capita variable insignificant. The Helsinki Protocol variable has a positive and significant coefficient, suggesting that signatories of this protocol have raised their emission efficiency faster, whereas the Oslo Protocol has had no statistically significant impact.⁽⁸⁾ Higher emissions in foreign contiguous countries raise domestic SO₂ efficiency, which is consistent with the game-theoretic expectation of strategic response if emissions in contiguous

⁽⁸⁾ This result does not necessarily contradict the literature that casts doubt on whether the Helsinki Protocol had any real effect on emission trajectories (eg Murdoch and Sandler, 1997; Ringquist and Kostadinova, 2005). None of these studies analyses emissions efficiency nor are they based on a global sample.

foreign countries are sufficiently positively correlated with transboundary deposits from these countries, and if the marginal-damage function is convex.

Finally, it is worth noting that we again find evidence of conditional convergence: conditional on the fixed effects and the other explanatory variables, the coefficient of the lagged dependent variable for CO₂ and SO₂ efficiency minus one is statistically significantly negative throughout.⁽⁹⁾

7 Conclusions and discussion

While globalisation has been widely blamed for environmental degradation at a range of scales, advocates of ecological modernisation have, nevertheless, suggested that it may have potential benefits. Central to this belief is the idea that linkages between countries provide enhanced opportunities for the international transfer and diffusion of environmentally beneficial innovations. Our goal in the present paper has been to empirically scrutinise two related claims. The first is that less pollution-efficient countries should improve their pollution efficiency faster than more pollution-efficient ones, as they incorporate ESTs and environmental policies already adopted in the more pollution-efficient countries. And second, transnational linkages accelerate the international spread of environmentally beneficial innovations and, therefore, improvements in environment efficiency. In order to test these claims, we used econometric techniques to examine the dynamics and determinants of CO₂ and SO₂ efficiency, in a panel encompassing up to 114 countries over the period 1980–2000.

With regard to the first claim, we find robust evidence of environmental catch-up and convergence. Tests both of β -convergence and σ -convergence confirm a growing similarity in levels of pollution efficiency over time. Convergence is evident both for our full sample, and the developing-countries subsample. Our results mirror previous findings for CO₂, but are derived from a much larger country sample (IEA, 1994; Lindmark, 2004; Mielnik and Goldemberg, 2000). Uniquely, our results suggest that catch-up and convergence are not restricted to CO₂, but are also apparent for SO₂, a pollutant with very different characteristics.

What might explain these dynamics? One possible explanation is that less pollution-efficient countries are catching up as they develop (less pollution-intensive) industrial structures, similar to those found in more pollution-efficient countries. However, it seems unlikely that the cross-national dynamics of pollution efficiency are primarily a function of structural convergence, as several studies suggest that structural change has played a comparatively small role in lowering emissions of CO₂ and SO₂ in more polluted countries (eg see Kaivo-oja and Luukkanen, 2002; Stern, 2002). Indeed, controlling for shifts in the share of industry value added in our panel data model, we still find robust evidence of convergence in CO₂ and SO₂ efficiency. Instead, a more plausible explanation for our findings is that less pollution-efficient countries are catching up with more pollution-efficient ones as they adopt new ESTs. Again, this interpretation would be consistent with recent decomposition analyses, which find that technological progression in the direction of lower pollution intensity has played an important role in reducing CO₂ and SO₂ emissions (de Bruyn, 1997; Kaivo-oja and Luukkanen, 2002; Shrestha and Timilsina, 1997; Wang et al, 2005). It would also tally with evidence pointing to the international spread of ESTs and environmental regulatory policies over time and, moreover, faster rates of diffusion in late adopters (Hilton, 2001; Perkins and Neumayer, 2005).

⁽⁹⁾ This cannot be directly observed from tables 2 and 3, but follows from the confidence intervals of the estimations.

With regard to the second claim, our findings provide broad support for arguments regarding the positive role of transnational linkages. Our estimations point to faster improvements in CO₂ and SO₂ efficiency in countries where a larger share of machinery and manufacturing imports derive from more pollution-efficient economies. However, we find no similar relationship for exports, suggesting that the convergence literature is correct in emphasising imports primarily as the leading vehicle for efficiency-enhancing technological change (Coe et al, 1997). While our estimation results say nothing about underlying drivers, one possible explanation for our result regarding imports concerns international technological and/or regulatory spillovers. Imports of machinery from pollution-efficient countries might be expected to embody high levels of environmental performance, contributing to improvements in domestic environment efficiency. Similarly, manufactured goods obtained from pollution-efficient countries are more likely to provide the impetus for investments by indigenous firms in more modern, environment-efficient technologies, particularly where they are required in order to remain price and/or quality competitive (Warhurst and Bridge, 1997). It is also possible that import ties with more environment-efficient countries may act as a conduit for the spread of environmentally progressive norms, policy lessons, and regulatory instruments, indirectly driving improvements in environment efficiency (Grubb et al, 2002).

We also find evidence that transnational investment linkages do matter, albeit only in the case of CO₂. We estimate that countries with a larger ratio of inward FDI to GDP experience faster improvements in domestic CO₂ emissions efficiency. This is consistent with previous work by Mielnik and Goldemberg (2002) on the relationship between energy intensity and FDI in a sample of developing countries. Yet it is also compatible with neoliberal claims about transnational corporations as cross-border carriers of environmentally superior technologies and management practices (OECD, 1998). Indeed, a plausible explanation for our finding is that TNCs have access to advanced energy-efficient technologies and, moreover, deploy these for competitive advantage in host economies. The combination of increased competition and knowledge spillovers means that indigenous firms follow suit by upgrading the energy efficiency of their processes and/or product technologies. Our finding that the stock of inward investment does not affect domestic SO₂ emission efficiency, of course, raises questions about the extent to which FDI influences other pollutants. Yet it is worth noting that levels of FDI in the power-production sector—which typically accounts for the vast bulk of domestic sulphur emissions—were comparatively small during our period of study.

Further reinforcing our findings that transnational linkages between countries positively shape environment efficiency, we find a role for countries' telecommunications connectivity. The idea that transnational information and communication networks support environmental upgrading is frequently discussed in the case-study literature (Falkner, 2006; Mason, 2005; Rock, 2002). Within these works, telecommunications technologies are portrayed as providing a conduit for the cross-border transfer of coercive pressures, as well as knowledge about environmental technologies, policies, and norms. Our study is unique in providing systematic empirical support for the environmental significance of telecommunications linkages and suggests that past large-*N* research may have overlooked a central channel of environmental convergence.

What are the wider implications of our findings? First, they counter suggestions that environmental progress is restricted to a handful of rich industrialised economies. The fact that environmental laggards are catching up with environmental leaders suggests that improvements in environment efficiency are, in fact, geographically widespread.

At least for the two pollutants investigated in the present study, more environmentally progressive countries are not racing further and further ahead, leaving behind a pack of struggling environmental laggards. Instead, it appears that environmentally beneficial innovations are diffusing across countries, with the result that efficiency improvements made in environmental frontrunner countries are globalising. Second, our findings suggest that advocates of globalisation are right to suggest that transnational linkages between countries can play a positive role, accelerating improvements in domestic environment efficiency (OECD, 1998). Geographic ties with more environment-efficient countries in particular would appear to provide opportunities for ESTs and environmental policies to diffuse.

At the same time, we would caution against overinterpretation of these and similar results. Despite supporting the idea of catch-up, the results presented here do not indicate that countries are converging on an ecologically sustainable path. Our findings simply suggest that countries are becoming more similar in the efficiency with which they use the environment to produce economic output. Indeed, if economic growth increases faster than growth in emissions efficiency, the net effect on the environment will remain negative. This appears to be the case for CO₂ emissions which, despite ongoing technological change in the direction of greater energy and/or carbon efficiency, continue to grow rapidly at the global level (IPCC, 2007). Free-market-driven technological innovation and diffusion is unlikely to be sufficient to address the CO₂ externality, pointing to the need for aggressive policy intervention both by developed-country and by developing-country governments.

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Appendix A
Table A1. Descriptive summary statistics.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
<i>CO₂ efficiency</i>					
ln emissions efficiency ($t - 1$)	1451	1.00	0.72	−0.99	3.51
Machinery and manufactured goods-import-weighted spatial lag ($t - 1$)	1451	0.75	0.16	−0.12	1.20
Machinery and manufactured goods-export-weighted spatial lag ($t - 1$)	1418	0.76	0.34	−0.56	2.21
Foreign direct investment stock	1451	19.22	33.94	0.00	439.76
Telecommunication principal component	1451	0.15	1.31	−0.42	10.13
ln GDP per capita	1451	6.51	1.00	1.73	8.50
Percentage industry value added	1451	32.27	9.17	7.85	72.69
<i>SO₂ efficiency</i>					
ln emissions efficiency ($t - 1$)	1448	−0.26	1.01	−5.54	4.26
Machinery and manufactured goods-import-weighted spatial lag ($t - 1$)	1448	0.16	0.41	−0.93	1.30
Machinery and manufactured goods-export-weighted spatial lag ($t - 1$)	1415	−0.03	0.47	−1.91	2.26
Foreign direct investment stock	1448	19.27	33.97	0.00	439.76
Telecommunication principal component	1448	0.14	1.30	−0.42	10.13
ln GDP per capita	1448	6.50	1.00	1.73	8.50
Percentage industry value added	1448	32.24	9.17	7.85	72.69
Helsinki Protocol	1448	0.30	0.77	0.00	2.77
Oslo Protocol	1448	0.25	0.57	0.00	1.95
ln contiguous emissions	1448	0.17	0.17	−0.02	1.04

Appendix B
List of countries in sample

Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Benin, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Congo (Republic of), Costa Rica, Côte d'Ivoire, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Estonia, Ethiopia, Finland, France, Gabon, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Ireland, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyz Republic, Latvia, Lebanon, Libya, Lithuania (SO₂ only), Luxembourg, Macedonia, Malaysia, Malta, Mexico, Moldova, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation (CO₂ only), Saudi Arabia, Senegal, Singapore, Slovak Republic, Slovenia, South Africa, South Korea (CO₂ only), Spain, Sri Lanka, Sudan, Sweden, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Yemen, Yugoslavia (CO₂ only), Zambia, Zimbabwe.

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