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Abstract

Arguments about the "positive" influence of growing transnational linkages have typically focused on their role in diffusing environmentally-superior innovations which help to raise countries' environment-efficiency. The present article empirically tests these claims by examining whether developing countries' linkages with more CO_2 and SO_2-efficient economies contribute to domestic improvements in CO_2 and SO_2-efficiency. Our large-N, statistical findings caution against some of the efficiency-oriented optimism voiced by supporters of globalization. Although imports ties with more pollution-efficient countries are found to spillover into improved domestic CO_2 and SO_2-efficiency, neither transnational linkages via exports, inward foreign direct investment (FDI) nor telephone calls appear to have any influence on domestic pollution-efficiency.

Keywords Transnational linkages; trade; spillover; developing; carbon dioxide; sulfur dioxide

1. Introduction

The period since the 1970s has been one of intense globalization. Through rising levels of trade, investment and telecommunications, countries have become increasingly interconnected, integrated and interdependent. For critics, the growth of transnational linkages has had negative environmental implications, particularly for developing countries (Clapp, 2001, Mason, 1997, Moody, 2007, O'Brien and Leichenkob, 2000). Hence, it is suggested that the incorporation of developing countries into the global economy has forced governments into a competitive race-to-the-bottom, has led to the development of pollution havens, and the dumping of "dirty" technology on the global South. Advocates of globalization, on the other hand, tell a different story. They argue that growing transnational linkages have accelerated the transfer and diffusion of environmentally-superior technologies, organizational practices and public policies to developing countries (OECD, 1997, Wolf, 2004). Rather than a negative force, cross-border connectivity has provided new opportunities for developing countries to "leapfrog" over the dirty stages of development, and to industrialize in more environment- and pollution-efficient ways (Goldemberg, 1998).[1]

Our contribution in the present article addresses this second set of claims. More specifically, we examine whether transnational linkages contribute to improvements in the pollution-efficiency[2] of developing countries. Empirically, we focus on two pollutants: carbon dioxide (CO_2) and sulphur dioxide (SO_2). These pollutants were

[1] For the purpose of this article, we use the terms environment-efficient and pollution-efficient interchangeably.
[2] As such, our study says nothing about absolute measures of pollutant emissions, with improvements in domestic pollution-efficiency simply indicating that countries are generating fewer emissions per unit of economic production/consumption.

selected because they are two major sources of global environmental change: CO_2 is the leading greenhouse gas (GHG) responsible for anthropogenically-forced climate change, while SO_2 is one of the most important pollutants contributing to acid deposition (IPCC, 2007).

A number of studies have investigated whether transnational connectivity, communication and exchange have been instrumental in lowering emissions (in absolute terms and/or per unit of output) for these gases, reaching mixed results about the influence of cross-national linkages on domestic environmental performance (Grimes and Kentor, 2003, Heil and Selden, 2001, Jorgenson, 2007, Mielnik and Goldemberg, 2002, Perkins and Neumayer, 2008). Our contribution advances on these studies in three areas. First, we examine three different forms of transnational linkage, namely: trade (imports and exports), inward foreign direct investment (FDI) and telecommunications. With the exception of Perkins and Neumayer (2008), previous studies have focused solely on the first two of these, and only in isolation (i.e. trade or investment, but not both).

Second, and most importantly, we use spatial lag variables to investigate the influence of all three forms of transnational connectivity on domestic pollution-efficiency in developing countries. Within the present context, these capture the pollution-efficiencies of foreign countries weighted by the degree of connectivity to these countries via trade, FDI and telephone calls. Although one study has previously used spatial lags to investigate the influence of trade on domestic pollution-efficiency (Perkins and Neumayer, 2008), neither FDI nor telecommunications linkages have been investigated in this way. Instead, studies have relied on geographically aggregated measures of cross-border connectivity (total trade or FDI openness), which contain no information about levels of pollution-efficiency in countries to which developing economies are linked. This is problematic: the domestic influence of cross-border linkages is not only likely to depend on a developing economy's overall level of connectivity to other countries, but also on the levels of environment-efficiency in the countries to which it is connected. By distinguishing between linkages to countries which are more or less pollution-efficient, the spatial lags deployed in the present article provide a more conceptually valid measure of the hypothesized influence of transnational linkages on domestic pollution-efficiency in developing countries.

Third, we use a dataset for CO_2 which runs up to 2005, the most recent year of data available from the International Energy Agency (IEA). We therefore go beyond several previous studies whose samples have ended in 2000 or before, including our own one which is closest in focus and design to the present article, Perkins and Neumayer (2008). Our more up-to-date sample is important in that we capture a period in history during which developed economies began to invest more heavily in technologies (and associated practices) to reduce carbon emissions – possibly influencing developing countries to do the same.

Our findings caution against some of the efficiency-oriented optimism voiced by supporters of globalization and, specifically, those who point to the "beneficial" influence of transnational linkages. Although higher pollution-efficiency in other countries are found to spillover into improved domestic CO_2 and SO_2-efficiency if foreign pollution efficiency is weighted by import shares, neither exports, inward FDI nor telephone call linkages appear to have any influence on domestic pollution-efficiency in developing countries. The rest of the article is organized as follows: section 2 develops our conceptual framework; section 3 details our research design; section 4 present results; and section 5 provides conclusions and discussion.

2. Conceptualizing spillovers via transnational linkages

The idea that contact, communication and exchange underpin the geographic spread of new innovations amongst members of a social system has long been recognized in theories of diffusion (Rogers, 1995). More recently, similar ideas of connectivity have been deployed to argue that transnational linkages lead to the spread of environmentally-superior innovations to developing countries, which directly or indirectly contribute to domestic improvements in environment-efficiency (Busch et al., 2005, Grubb et al., 2002, Wallace, 1996).

Directly, improvements in environment-efficiency can come about through the cross-national diffusion of technological innovations, notably those with emissions lower than existing technological configurations (Huber, 2008, Perkins and Neumayer, 2005, Stern, 2002, 2005). Advances, particularly since the 1970s, have led to the development and deployment of a range of technologies which significantly reduce resource and pollution-intensity. Thus, end-of-pipe (EOP) technologies have played an especially important role in abating SO_2 emissions, while efficiency-enhancing innovations in process technologies have helped to reduce emissions of both CO_2 and SO_2.[3] Accompanying these developments have been innovations in operating practices – ranging from new, more efficient ways of operating machinery, through to environmental

[3] Included within the suite of process-related technological changes has been fuel-switching to less pollution-intensive energy sources (e.g. from coal to natural gas).

management systems (EMSs), which help firms to identify, plan and implement improvements in environmental performance.

Transnational linkages may also diffuse policy innovations, which by themselves do not lead to improvements in environment-efficiency, but incentivise the domestic uptake of more environment-efficient performances, practices and technologies (Busch et al., 2005, Stern, 2007). Such policies include government environmental regulations, expressly promulgated to address specific forms of environmental degradation (e.g. emission standards for SO_2 to tackle terrestrial acidification). Less obviously, non-environmental policies may also play a role, altering the choices of domestic actors in ways which lead to improvements in environment-efficiency. As an example: policies to liberalize energy markets have been known to improve CO_2-efficiency in electricity generation by promoting a switch towards less carbon-intensive fuel types and more efficient plant designs (IEA, 2001).

The international spread of environmentally-superior innovations is likely to be especially significant in the context of developing countries (Goldemberg, 1998, Marcotullio et al., 2005). The vast majority of these states have limited innovative capacities and, with a handful of exceptions, little expertise in the development of more advanced, environment-efficient technologies[4]. Improvements in domestic environment-efficiency are therefore likely to depend significantly on technology transfer from more environment-efficient economies (Perkins, 2003). Likewise, developing countries have also lagged in the introduction of environmental regulations, limiting the incentives for the adoption of such technologies. As such, the implementation of policies already

[4] Yet it is nevertheless worth noting that certain developing countries have been active in innovating, commercialising and manufacturing a range of environment-efficient technologies (e.g. solar collectors, wind turbines).

adopted in more environmentally progressive states holds the potential to bring about significant improvements in environment-efficiency, albeit indirectly working through environmentally-superior technology and organizational practices (Hilton, 2006).

The literature identifies two main ways in which transnational linkages accelerate the cross-border spread of new innovations. One set of mechanisms centre on learning. Through contact, communication and exchange, actors may come to learn about innovations deployed elsewhere, together with their costs, benefits and feasibility (Simmons and Elkins, 2004). Along these lines, a sizeable literature has documented how cross-border learning has stimulated actors in one country to adopt innovations already deployed elsewhere, whether for instrumental reasons (e.g. firms believe that a new technology will help to increase profits) or reputational ones (e.g. governments emulate the environmental policies of more progressive states in order to avoid looking backwards) (Drezner, 2001). Another oft-cited set of mechanisms centre on competition (Grubb et al., 2002, O'Neill et al., 1998). Transnational linkages potentially expose domestic actors to competitive pressures which, directly or indirectly, stimulate the adoption of technologies, practices, policies and/or performances similar to their counterparts in other countries. For example, international competition from lower cost producers of steel may encourage domestic firms in developing countries to invest in more energy-efficient technologies and practices, such that they converge upwards in levels of CO_2-efficiency with their foreign counterparts (Perkins, 2007).

In practice, globalization is a multi-faceted process, and there are multiple ways in which any one developing country can be linked to any other set of countries. We focus here on three broad and widely-discussed transnational linkages, created respectively by international trade, inward FDI and telecommunications.

2.1 International trade

Trade has featured prominently in accounts of how worldwide economic integration can contribute to environmental sustainability – particularly in developing countries (OECD, 1997, Wolf, 2004). Core to the assumed importance of trade is its role in diffusing more modern, environment-efficient technologies. Most obviously, international trade (via imports) allows developing countries to acquire more advanced, environmentally-superior technologies innovated in other countries, notably from economies with requisite design and/or manufacturing competencies. As an example: a low-income country could improve CO_2-emission efficiency in its power sector by purchasing the latest, thermally-efficient plant designs from developed-country vendors.

Trade may also stimulate demand for more environment-efficient technologies in developing countries. Through various social interactions created by imports and exports, domestic firms may come to learn about new technologies. Indeed, businesses may pay particular attention to the choices of their counterparts in export markets or in countries which have successfully penetrated the domestic economy via imports, both of which are likely to serve as important “reference” groups (O'Neill et al., 1998). Thus, domestic firms may adopt a new technology because their foreign peers are doing so, fearing that they may otherwise fall behind. More directly, price or quality competition from imports or in export markets may stimulate developing-country firms to upgrade their technologies to more modern designs, which embody higher levels of environment-efficiency (Grubb et al., 2002, Jenkins et al., 2002). Of course, there will be instances where competitive pressures will have precisely the opposite effect, incentivizing actors to reduce costs in ways that inhibit efficiency-enhancing capital investments (e.g. purchase of a new, more energy-efficient process unit) or operating expenditures (e.g. not running end-of-pipe sulfur devices). Yet, particularly for firms which compete with producers from more environment-efficient economies, we believe these "negative" dynamics are likely to be more than offset by the "positive" ones of competition-driven technological modernization.

Trade has also been implicated in the diffusion of more progressive environmental policies which, in turn, stimulate investments in technologies which improve environment-efficiency. Most famously, Vogel has hypothesized a "trading-up" effect, whereby more stringent standards in high-regulating foreign markets spillover into lower-regulating jurisdictions via exports (Vogel, 1997). Typically, this is explained in terms of coercive supply-chain pressures from environmentally-demanding buyers, but scholars have also pointed to the importance of reputational motives (Drezner, 2001, Perkins and Neumayer, forthcoming).

Regardless, we argue that what is likely to be important is not only a developing country's overall volume of trade, but with whom it trades. Imports or exports with pollution-inefficient countries are unlikely to spillover into significantly improved domestic levels of environment-efficiency. Pollution-inefficient countries are likely to be characterized by dirty technologies, a low uptake of efficiency-enhancing organizational practices, and lax environmental regulations. The result: technology imported from these countries will embody low levels of pollution-efficiency, there will be fewer opportunities to learn from (or otherwise be influenced by) efficiency-enhancing organizational practices and progressive environmental policies, and competitive pressures for investments in more modern, efficient technologies will be lower.

Previous statistical work lends considerable empirical weight to claims about the role of trade in accelerating the spread of environmentally-superior technologies, organizational practices and public policies. A number of large-N, quantitative studies have shown that more modern, environment-efficient technologies have diffused more rapidly in economies more open to international trade (Perkins and Neumayer, 2005, Reppelin-Hill, 1999, Wheeler and Martin, 1992). Similarly, trade has been found to be positively correlated with the uptake of more progressive environmental policies, including those addressing air pollution (Frank et al., 2000, Popp and Lovely, 2008). Studies have also shown that if a country mainly exports to other countries with a high number of (potentially) efficiency-enhancing EMS standards (namely, ISO14001), this tends to spillover domestically into a higher number of EMS adoptions (Prakash and Potoski, 2006, Perkins and Neumayer, forthcoming).

Turning to studies which have directly investigated the relationship between measures of trade and pollution emissions, Heil and Selden (2001) show that trade openness is positively correlated with total CO_2 emissions in developing countries; while Lopez and Galinato (2005) finds mixed results for the influence of trade openness on deforestation-derived carbon emissions, again in a sample of developing countries. Neither of the above studies distinguishes between trade with pollution-efficient and inefficient countries, uses emissions-efficiency as a dependent variable, or investigates pollutants other than CO_2. The one study that does these things, Perkins and Neumayer (2008), shows that developing countries where a greater share of imports are from CO_2 and SO_2-efficient countries have higher domestic pollution-efficiencies for these gases. Yet the authors do not find a similarly statistically significant relationship between exports and domestic pollution-efficiency.

2.2 Foreign direct investment (FDI)

The idea that inward FDI is instrumental in the diffusion of environmentally-superior innovations and performances rests on a set of claims about the direct and indirect effects of transnational corporations (TNCs) (Andonova, 2003, UNCTAD, 2007, Wallace, 1996). Directly, it is suggested that transnationals often incorporate the latest, environment-efficient technologies in their investments in developing countries (OECD, 1997). Many of the world's most advanced technologies – including those capable of improving environmental-efficiency – are innovated, owned and operated by TNCs (UNCTAD, 2007). Moreover, transferring the latest technologies with high levels of environment-efficiency potentially allows TNCs to exploit their ownership-based advantages over domestic competitors, e.g. an automobile with a modern, fuel-efficient engine characterized by high levels of embodied CO_2-efficiency may command a price premium over domestic rivals, who only have access to lower performance, fuel-inefficient engine designs (Perkins, 2007). Adopting the same technologies through regional and/or global corporate networks in both developing and developed countries may also be more cost effective, e.g. it may be cheaper for an automobile TNC to manufacture the same advanced, fuel-efficient engine for all its markets, rather than a different design for each one. Further, implementing environment-efficient technologies in developing-country foreign affiliates and subsidiaries may reduce the risk of environment incidents, and damaging claims of "double-standards." Similar points have been made about the propensity of developed-country transnationals to adopt beyond-compliance corporate environmental standards, policies and organizational practices in developing economies (Angel et al., 2007).

Yet just as potentially significant as these direct effects from FDI are various indirect ones. A growing body of work has therefore speculated that the local presence of TNCs in developing countries may be instrumental in technological, organizational and environmental upgrading amongst domestic firms (Garcia-Johnson, 2000, Jeppesen and Hansen, 2004, UNCTAD, 2007). Within this line of argument, it is suggested that foreign transnationals may have a demonstrative effect, highlighting the existence, feasibility and benefits of more modern, environment-efficient technologies, operating practices and corporate voluntary standards (Huber, 2008). Domestic firms in developing countries may emulate their foreign peers, adopting new technologies, operating practices, etc., which are seen as contributing to the success of TNCs. The local existence of TNCs may also give rise to various knowledge spillovers, which facilitate the adoption, implementation and replication of more advanced, environment-efficient technologies amongst domestic firms, e.g. employees of a TNC subsidiary learn technological know-how which they diffuse to local competitors through labor mobility (UNCTAD, 1999). TNCs may also give rise to new or enhanced competitive pressures which prompt local firms in developing countries to take action to improve their competitiveness. Again, this may involve investments in more modern technologies, operating practices and standards, which – because they embody higher levels of environmental performance as an integral feature of their design – help to raise firms' environment-efficiency.

It is also possible that enhanced competitive pressures from TNCs may retard, or else have limited effects in stimulating, efficiency-enhancing investments amongst competitors in the host economy. Hence, the presence of TNCs in the local market may reduce the profitability of domestic firms, limiting their willingness, ability and propensity to invest in more modern plant, equipment and operating practices. Furthermore, unable to compete on the basis of technology leadership, domestic firms might pursue a cost minimization strategy, e.g. producing cars with older, less environment-efficient engine designs, but which are cheaper than those of their foreign rivals. Yet it is our belief that these are short-term dynamics and that, across the economy as a whole, competition from TNCs is more likely to raise than reduce a country's environment-efficiency.

As with trade, we argue that the influence of foreign TNCs in developing countries is likely to depend on its country of origin, with FDI inflows from more environment-efficient countries having a greater pollution-efficiency enhancing effect than similar investment from less environment-efficient countries (c.f. Prakash and Potoski, 2007, Perkins and Neumayer, forthcoming). Although there will inevitably be exceptions, TNCs from less pollution-efficient countries – which presumably lag in terms of environmentally-significant technology and organizational practices – are less likely to "transfer" efficiency-raising innovations to developing countries, and therefore impact domestic pollution-efficiency. Nor, for the very same reasons, are they likely to stimulate domestic upgrading in the direction of greater environment-efficiency via learning or competitive effects.

Compared to trade, however, empirical support for the assumed "positive" role of FDI is far more mixed. Amongst the few large-N, quantitative studies which have directly investigated the links between aggregate FDI inflows and the uptake of more modern, environment-efficient technologies, scholars have found little evidence of a positive relationship (Andonova, 2003, Perkins and Neumayer, 2005). Statistical research which has relied on geographically aggregated measures of FDI inflows has reached similar results when it comes to the spread of EMS standards (Neumayer and Perkins, 2004, Prakash and Potoski, 2006).

More directly, Grimes and Kentor (2003) find inward FDI stock has a positive effect on absolute CO_2 emissions in developing countries, while Jorgenson (2007) shows a positive link in developing countries, albeit between primary sector total inward FDI stocks and the growth of CO_2 emissions from agriculture. Again, based on an absolute measure of emissions, He (2006) estimates that Chinese provinces with a greater FDI stock have marginally higher levels of SO_2 emissions. Turning to studies which focus on measures of pollution normalized by GDP, Mielnik and Goldemberg (2002) find that FDI and domestic CO_2-intensity (i.e., the reverse of efficiency) is negatively correlated in developing countries, although it is worth noting that their result derives from a simple correlation without control variables. Using a larger sample and an estimation model which features relevant control variables, Perkins and Neumayer (2008) find that FDI has a positive and statistically significant impact on CO_2 emissions-efficiency in developing countries, but no statistically discernible influence on SO_2. The present article advances on these studies by using geographically disaggregated data to investigate the influence of inward FDI linkages on cross-national pollution-efficiency spillovers.

2.3 Telecommunications

While much of the focus of recent statistical work has been on trade and, to a lesser extent, FDI, there is growing recognition that international telecommunications may also be instrumental in diffusing environmentally-superior innovations – and, more broadly, performances – across borders (Mol, 2006, Roberts and Thanos, 2003). Cross-border communications are another way in which developing-country firms might come to learn about new, more environment-efficient technologies or associated organizational practices, innovated and deployed in other economies (Gong and Keller, 2003). This learning may, in turn, stimulate domestic adoption of similar innovations by altering perceptions about their feasibility, financial payoffs and overall value. As an example: it is not implausible to suggest that firms located in developing countries which communicate intensively with more environmentally progressive states stand a greater chance of learning about, and possibly being influenced to adopt, environment-efficient technologies and organizational practices.

More so than trade or FDI, cross-border communications might also play a role in generating domestic demand from civil society for environmental innovations and performances found elsewhere. Through remote communications, citizens in developing countries may come to learn about environmental technologies, practices, policies and performances elsewhere, potentially creating new, or redefining existing, expectations regarding governments and firms. For example, on learning about stringent SO_2 emission regulations adopted in countries with which they communicate more, organized elements in civil society may exert pressure on domestic politicians to match their foreign peers. Anecdotal evidence exists of such "learning-by-comparison" in public environmental policy in developing countries, where civil society has called on their governments to adopt policies similar to those already deployed in more progressive, developed economies, citing the experience of the latter as evidence of the feasibility of stringent regulations (Perkins, 2007, Rock, 2002).

The influence of telecommunications has received very little attention in the empirical literature. Using geographically aggregated data on international telephone traffic, Wong (2004) shows that countries which communicate more with highly productive economies enjoy higher rates of domestic productivity growth. Only one large-N, quantitative study has directly investigated the influence of telecommunications on domestic environmental outcomes. Perkins and Neumayer (2008) show that developing countries characterized by greater tele-connectivity – measured by the principal component of the number of internet users per capita and international telephone traffic – enjoy a faster rate of improvement in domestic SO_2-efficiency, but not CO_2-efficiency. However, based on aspatial data, it remains unclear as to whether these results hold when using geographically disaggregated data which captures levels of pollution-efficiency in foreign countries with which countries communicate more intensively.

3. Research design

3.1 Dependent variable and sample

The dependent variable in our estimations is a country's pollution-efficiency, i.e. GDP divided by emissions. Data for CO_2 emissions is obtained from IEA (2007) and our sample covers the period 1980-2005. A lack of data means that our SO_2 sample covers a shorter period, 1980-2000, with data taken from Stern (n.d.). Owing to the fact that our telecoms data do not stretch as far back as 1980, the respective samples start in 1983 in the regressions where the spatial lag with telecommunications as connectivity variable is included. GDP at exchange rates is known to underestimate effective purchasing power in lower-income countries. We therefore use GDP measured on a purchasing power parity (PPP) basis using data from IEA (2007).

The unit of analysis is the country year. Our estimations cover up to 98 developing countries for CO_2 and up to 92 countries for SO_2, where the sample size is determined entirely by the availability of data for the dependent and explanatory variables. After one of the current World Bank classification schemes, developing countries are defined as all states which are not members of the Organization for Economic Cooperation and Development (OECD). The only exceptions are the Czech Republic, Hungary, the Slovak Republic and South Korea which, although currently members of the OECD, we define as developing because they have been outside this high-income group for the largest part of our study period.

3.2 Estimator

We estimate the following model (*i* stands for country, *t* for time):

$$(1)\ \ln y_{it} = \alpha_i + \beta_1 \ln y_{it-1} + \beta_2 \sum_k w_{ikt-1} \ln y_{kt-1} + \beta_3 \ln GDPpc_{it} + \beta_4 \%indust_{it} + \delta_t + u_{it}$$

where y_{it} is our dependent variable, α_i represent country-specific fixed effects, $\ln y_{it-1}$ is the temporally lagged dependent variable, $\sum_k w_{ikt-1} \ln y_{kt-1}$ represents the spatial lag variable described in more detail below, $GDPpc_{it}$ is a country's per capita income, $\%indust_{it}$ its industrial share of GDP, δ_t represent year-specific fixed effects and u_{it} is the error term.

The country-specific fixed effects account for unobserved country differences influencing domestic pollution-efficiency which do not vary, or vary very little over time, and which might be correlated with our explanatory variables. Included here are factors such as cultural differences which lead certain countries to exhibit greater normative commitment towards environmental degradation or moral responsibility for the global commons, as well as natural resource endowments, particularly of fossil fuels (e.g. see Stern, 2005). The year-specific fixed effects capture time-specific global trends influencing emissions efficiency, e.g. growing worldwide awareness of the negative externalities associated with CO_2 and SO_2. Country- and time-specific fixed effects are also necessary to prevent spurious regression results for the spatial lag variables as they account for unobserved spatial heterogeneity and common shocks and common trends (Plümper and Neumayer, forthcoming).

We estimate equation (1) with Arellano and Bond's (1991) dynamic generalized method of moments (GMM) instrumental variables estimator with robust standard errors. This estimator is necessary because of the simultaneous inclusion of the temporally lagged dependent variable and country-specific fixed effects, which would cause Nickell (1981) bias in a simple fixed effects estimation. The Arellano and Bond estimator has the important advantage that the spatial lag variables can be explicitly specified as endogenous, i.e. their past and contemporaneous values are allowed to be correlated with the error terms. The estimator works by first-differencing equation (1), which eliminates the country-specific fixed effects, and by using past levels of the lagged dependent variable and the endogenous variables lagged by two or more periods as respective 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 can be tested and the test results fail to reject this assumption.

3.3 Spatial lag variables

As noted earlier, an important advance of the present study is to use spatial lags to estimate the influence of all three forms of spatial interdependence, i.e. interdependence working via trade, FDI and telecommunications. The spatial lags allow us to investigate whether higher levels of pollution-efficiency in other countries "spillover" domestically in terms of higher emissions-efficiency. Formally, a spatial lag variable is specified as the sum of the dependent variable in other countries (i.e. CO_2 and SO_2-efficency) weighted by a connectivity matrix, i.e. as $\sum_k w_{ikt} y_{kt-1}$, where *k* represents all countries other than country *i* and w_{ikt-1} measures the connectivity between country *i* and country *k*. In the present article, we use four distinct spatial lag variables for our respective measures of connectivity (i.e. imports, exports, FDI and telecommunications), each one comprising a different connectivity matrix. The connectivity-matrix is row-standardized, i.e. the weights in each row sum to unity. Row standardization is commonly used in the literature and makes substantive sense for our analysis since our primary interest is the identity of the major trade, investment and communication partners, and not the total exposure of countries to related influences. We temporally lag our spatial lag variables by one year because it is unlikely that transnational linkages would have an instantaneous effect on domestic pollution-efficiency.[5] Note that the sample used for generating the spatial lag variables comprises all countries, including developed ones, as otherwise they would only capture diffusion among developing economies.

The trade connectivity matrix is constructed using UN (2008) data on bilateral machinery and manufactured goods imports and exports. We create two separate spatial lag variables, one in which machinery and manufactured goods imports of country *i* from countries *k* make up the connectivity variable, and another one in which exports from country *i* to countries *k* are used. After Perkins and Neumayer (2008), we restrict our focus to machinery and manufactured goods, since they are far more likely to have a substantive influence on domestic CO_2 and SO_2-efficiency than other categories of

[5] It is impossible to know the "correct" temporal lag length. If we temporally lag the spatial lag variables by two, three, four and five year lags, respectively, then results remain similar to the ones reported below.

imports/exports (e.g. foodstuffs). Machinery is involved in many (potentially) pollution-intensive processes and, furthermore, its environmental performance should plausibly be affected by international trade flows. For example, environment-efficient capital equipment (e.g. advanced, energy-efficient steel plant) imported by developing countries is likely to be instrumental in lowering domestic emissions per unit of output, especially if it substitutes for older, environment-inefficient technology. Trade in manufactured goods might similarly have potentially significant implications for domestic environment-efficiency. Directly, imports of manufactured goods from more pollution-efficient countries (e.g. automobiles) embodying high levels of in-use environment-efficiency may contribute to reductions in domestic emissions. Indirectly, competition from more price and/or quality competitive manufactured goods – whether from imports or in export markets – may stimulate domestic firms to upgrade their production and/or product technologies, resulting in the adoption of more modern technologies with higher levels of environmental performance.

Our second connectivity matrix, which captures the influence of foreign investment, is constructed using bilateral inward FDI stocks in country i originating from countries k as the connectivity variable, with data from UNCTAD (2008). Unlike our trade measure, data limitations mean that we are unable to restrict our analysis to investments in economic sectors most likely to influence pollution-efficiencies, e.g. electricity generation, steel, etc. Still, our spatial lag with FDI as connectivity variable advances on the geographically aggregated, total FDI based variables used in previous work concerned with the link between foreign investment and pollution-efficiency/intensity, in that it captures information on levels of pollution-efficiency in investor countries (Grimes and Kentor, 2003, Mielnik and Goldemberg, 2002, Perkins and Neumayer, 2008). We focus on FDI stocks. FDI flows data are frequently characterized by significant inter-annual variations and therefore provide a potentially misleading measure of the overall influence of foreign investors on domestic technology, organizational practices and policy in any one year.

Our final connectivity matrix specifies connectivity according to bilateral telephone call traffic (in minutes) between country *i* and countries *k*, using data from TeleGeography (2007). Although these data have previously been used to explore cross-border productivity spillovers (Wong, 2004), ours is (to the best of our knowledge) the first study to use this dataset to examine whether remote communications linkages between countries contribute to environmental spillovers.

3.4 Control variables

We additionally include three control variables in our estimations.[6] First, using data from IEA (2007), we add GDP per capita in PPP to take account of the fact that wealthier economies should plausibly have higher levels of pollution-efficiency. On the demand-side, economists have suggested that the environment is a normal good, in that demand for environmental quality is likely to rise with per capita income (Grossman & Krueger, 1995). A more sociological interpretation of these dynamics can be found in the work of Inglehart (1977) who suggests that growing material affluence has led people to turn their attention towards post-materialist needs and values, including a greater concern for quality of life issues, such as environmental sustainability. Indeed, because wealthier

[6] Results are very similar if we exclude the control variables from the estimation model.

populations are also typically better-educated, we might expect them to demonstrate greater awareness, concern and engagement with environmental degradation. This will include issues such as future anthropogenic climate change, which people in wealthier countries have not yet experienced directly, but may nevertheless have learnt about and developed concern.

Either way, responding to popular concerns and demands, governments in wealthier countries are likely to adopt more stringent environmental regulations, while private firms should be more willing to engage in beyond-compliance initiatives to manage their environmental performance. These predications are largely borne out by the empirical record, which shows that public and private commitment towards environmental protection rises with per capita income (e.g. Dasgupta et al., 2001, Neumayer and Perkins, 2004).

On the supply-side, domestic actors should be better-placed to be able to afford the costs of purchasing modern, environment-efficient technologies, many of which are more expensive on a capital-only basis (Perkins, 2003). Wealthier economies also have more advanced technological capabilities. They are therefore likely to be better-placed to innovate, manufacture and, of critical importance here, effectively implement, operate and maintain advanced, environment-efficient technologies. Note, the motives for acquiring and implementing these technologies may be non-environmental (e.g. to save on energy costs), although they may deliver significant gains in environment-efficiency. Adding a variable for GDP per capita allows us to control for these income-related differences.

A second control variable is the share of industry (comprising mining, manufacturing, construction, electricity, water and gas) in GDP. Industry is a major source of CO_2 and SO_2 emissions such that more industry-intensive economies will, on a like-for-like basis, have proportionately lower levels of pollution-efficiency for these gases. By controlling for industry share, we are better able to isolate the influence of structural differences (which are not of central concern here) from differences in the state of technology and organizational practices (which are of direct concern), and therefore reduce the likelihood of generating spurious findings.[7]

Third, we include a temporally lagged dependent variable, which controls for the possibility of (conditional) convergence in pollution-efficiency, i.e. countries with low levels of domestic CO_2 or SO2-efficiency might well improve their pollution-efficiency faster than countries with high levels of pollution-efficiency, such that the pollution-efficiencies of different countries should converge over time.[8] Conceptually, cross-national convergence is likely because gains in domestic pollution-efficiency are typically easier, cheaper and quicker to achieve where the baseline efficiency is low, e.g. technologically lagging countries can take advantage of efficiency-enhancing learning investments made by leading countries (Marcotullio et al., 2005; Perkins and Neumayer, 2005; Stern, 2007).

[7] The results are very similar if we exclude these two control variables. The spatial lag with exports as the transnational linkage variable becomes statistically significant if entered on its own for both CO_2 and SO_2-efficiency, but only the spatial lag with imports as the transnational linkage variable is significant if the spatial lags are entered simultaneously into the estimations.

[8] The convergence is called conditional since it is conditional on the other explanatory variables. Formally, there is evidence for conditional convergence if the coefficient of the lagged dependent variable for CO_2 and SO_2-efficiency minus one is statistically significantly negative.

4. Results

Tables 1 and 2 show our results for CO_2 and SO_2-efficiency, respectively. We first enter each spatial lag separately and then all spatial lags combined in one model. The results provide only mixed support for the role of transnational linkages in fostering cross-border spillovers of pollution-efficiency into developing countries. We find that our spatial lag working via import linkages has a positive and statistically significant effect on levels of domestic pollution-efficiency for both CO_2 and SO_2. That is, our results indicate that the more CO_2 and SO_2-efficient foreign countries from where a particular economy mainly imports its machinery and manufacturing goods, the higher are domestic levels of pollution-efficiency for these gases in the importing country. The result is the same regardless of whether this spatial lag is entered separately into the regressions or in combination with the other spatial lags.

<<INSERT TABLES 1 and 2 ABOUT HERE>>

Yet we fail to find the same result for exports. Our spatial lag based on exports as connectivity variable is statistically insignificant for both CO_2 and SO_2. We also find that neither FDI inflows nor telephone call linkages appear to act as conduits for cross-border spillovers of environmental efficiency. In both sets of regressions (i.e. where they are entered individually or in combination with the other spatial lag variables), the spatial lags working via inward FDI and telephone calls as connectivity variables have no statistically discernable influence on levels of domestic CO_2 or SO_2-efficiency in developing countries.

Finally, we turn to the control variables. As expected, GDP per capita is significantly positively correlated with both CO_2 and SO_2-efficiency in all but one of the estimations, most likely reflecting the greater awareness of environmental externalities in wealthier economies, greater demand for environmental quality, and an enhanced ability to respond to these concerns and demands. Also in line with expectations, the estimated coefficient for share of industry in value-added is negative and statistically significant, with one exception. Finally, as expected, we find evidence for conditional convergence in that the coefficients of the temporally lagged dependent variable for CO_2 and SO_2-efficiency minus one are statistically significantly negative throughout.[9]

5. Conclusions and discussion

In recent debates, advocates of neo-liberal reform have tended to steer-clear of (absolute) scale-effects in discussing the environmental implications of globalization in developing countries. Instead, they have preferred to focus on (relative) metrics of eco-efficiency, arguing that transnational contact, communication and exchange can enhance the efficiency with which countries utilize the environment to generate economic output, either as a source or sink. Our intervention in the present article empirically scrutinizes this efficiency-oriented optimism by examining whether developing countries' linkages to other countries impact on domestic pollution-efficiency for these important sources of global environmental change.

[9] This cannot be directly observed from tables 1 and 2, but follows from the confidence intervals of the estimated coefficients.

Our results provide only mixed support for the alleged environment efficiency-enhancing effect of transnational linkages in the context of developing countries. Only one of our constructs of global connectivity and interdependence emerges as a statistically significant predictor of domestic pollution-efficiency. Hence we find that the more environment-efficient the countries from which a developing country mainly imports its manufactured and machinery goods, the higher domestic levels of pollution-efficiency for these gases. However, if the developing country exports machinery and manufactured goods to more pollution-efficient economies, this has no statistically significant influence on either domestic CO_2 or SO_2-efficiency.

Although Perkins and Neumayer (2008) reached a broadly similar result, our finding for exports is nevertheless surprising. One possible explanation for the discrepancy is that, while countries may "import" high levels of embodied environmental performance by acquiring capital and manufactured goods from pollution-efficient countries, no equivalent mechanism exists in the case of exports. Also, while many developing countries predominantly import high value-added goods (e.g. capital items, technologically-advanced manufactures), they largely export low value-added goods (e.g. textiles, foodstuffs). Within developed-economy exports markets, customers are unlikely to be greatly concerned about CO_2 or SO_2 emissions generated during the production of low-value goods, nor about their in-use emissions which tend to be comparatively insignificant. Hence our findings might be explained by the different structure of imports and exports. Another possible explanation is that the efficiency-enhancing effect of imports – especially via competitive effects – is more diffuse because it potentially affects all domestic firms in a particular sector. Conversely, exports are only likely to stimulate efficiency-enhancing upgrading amongst firms who market their goods in pollution-efficient countries, which may not include all industry participants. In the absence of further research, however, we cannot say with any certainty which one – or indeed combination – of these possible explanations accounts for the result.

Another interesting result is that the pollution-efficiencies of a developing country's major source countries of inward FDI stocks do not affect domestic CO_2 and SO_2-efficiency. This goes against many assumptions about the role of TNCs as carriers of environmentally-superior innovations to lower-income countries, raising questions about whether FDI from more pollution-efficient economies actually has an environment-efficiency enhancing effect. Of course, it could be that our inclusive, all-sector measure of FDI is too broad to capture the hypothesized substantive influence of TNCs, which is most likely to arise in the context of pollution-intensive sectors. Unfortunately, sectorally disaggregated bi-lateral FDI data with wide geographic coverage do not exist, meaning that we cannot test this thesis.

Yet sectoral effects are unlikely to explain the discrepancy between our result for FDI and previous, large-N work which has found that inward FDI is associated with higher levels of CO_2-efficiency (Mielnik and Goldemberg, 2002, Perkins and Neumayer, 2008). Instead, these differences are most likely rooted in the distinctive way in which these respective studies have modeled and measured FDI. Hence past "positive" findings have been based on aggregate measures of FDI stock/flows and therefore capture the relationship between overall levels of connectivity to all other countries and domestic environment-efficiency. Conversely, our study does not capture countries' overall connectivity, but rather levels of environment-efficiency in other countries weighted by these respective countries' share of total inward FDI stocks. Therefore, previous studies and the present one measure two different aspects of the same phenomenon, suggesting that it would be wrong to conclude that the results of the former are spurious. We would be inclined towards placing greater store on our findings, since they derive from an analytical model and measure which better represents theoretically-derived causal mechanisms hypothesized to account for cross-border environmental spillovers, i.e. accounting for the fact that inward FDI from pollution-efficient countries should plausibly have a greater influence on domestic pollution-efficiency than FDI from pollution-inefficient countries. However, we cannot discount the possibility that what matters in raising domestic environment-efficiency is the overall volume of FDI, rather than higher levels of environment-efficiency in investing economies.

We similarly draw a blank when it comes to telecommunications. As with exports and inward FDI, our econometric estimations suggest that pollution efficiencies in a developing country's major telecommunication partner countries do not affect domestic levels of domestic CO_2 and SO_2-efficiency. This does not necessarily mean that cross-border telecommunications play no role in diffusing environmental innovations and performance. Besides, our measure of cross-border communications is a broad one, failing to capture specific geographic patterns of communication between those actors whose interactions are most likely to contribute to environmental spillovers, e.g. government bureaucrats, powerful environmental NGOs, etc. A challenge for future research will be to (re-)investigate the influence of remote communications using more refined data for policy-relevant actor-networks.

Two broader lessons emerge from this research. One is that we must be cautious towards generalized claims about the environmental benefits of transnational linkages, connectivity and exchange. In our study, being connected to foreign countries via imports of machinery and manufacturing goods appears to act as a conduit for the diffusion of pollution-efficiency into developing countries for two key pollutants implicated in global environmental change. Yet the fact that neither linkages via exports, inward FDI nor telephone calls have an influence on domestic pollution-efficiency in our research raises questions as to whether all forms of global linkage systematically have an unambiguously "positive" influence in developing countries.

Another lesson is methodological. Much of the large-N, statistical literature which has investigated the role of transnational linkages in the diffusion of environmental innovations and performance has done so in an aspatial manner. Studies have ignored the specific geometry of cross-border linkages, relying instead on aggregate measures of exposure to external influences. Our research suggests that the way in which researchers specify "globalization" may have significant implications for our understanding of its environmental implications. Revealing here are the differences between the findings of the present article, which uses spatial lags, and our previous work, which mainly makes use of aggregate measures of connectivity (Perkins and Neumayer, 2008). These disparities serve as a reminder that analysts' research design and specification can have a major influence on the inferences that they derive regarding the anthropogenic dynamics of global environmental change.

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Table 1. Estimations for CO_2-efficiency.

	(1)	(2)	(3)	(4)	(5)
ln emissions efficiency (t-1)	0.752	0.743	0.752	0.811	0.675
	(14.82)**	(12.71)**	(27.66)**	(27.56)**	(11.37)**
Machinery and manuf. import	0.213				0.184
weighted spatial lag (t-1)	(3.75)**				(3.02)**
Machinery and manuf. export		0.030			-0.007
weighted spatial lag (t-1)		(1.28)			(0.28)
FDI stock stock			0.046		0.022
weighted spatial lag (t-1)			(1.76)		(1.21)
Telecommunication				-0.032	0.003
weighted spatial lag (t-1)				(1.80)	(0.21)
ln GDP p.c.	0.113	0.100	0.132	0.131	0.169
	(2.79)**	(2.57)*	(5.21)**	(3.26)**	(3.75)**
% Industry value added	-0.003	-0.005	-0.004	-0.005	-0.005
	(3.08)**	(2.78)**	(4.54)**	(5.21)**	(3.32)**
Observations	1391	1356	1799	1799	1129
Countries	92	92	98	98	89
Test of no second-order auto-	-1.74	-0.85	-0.624	0.611	-0.980
correlation (p-value in brackets)	(0.082)	(0.393)	(0.532)	(0.541)	(0.329)

Arellano and Bond (1991) GMM estimation. Coefficients of year-specific time dummies and constant not reported. Dependent variable is ln emissions-efficiency. Absolute robust z-statistics in parentheses. * significant at 5%; ** significant at 1% level.

Table 2. Estimations for SO_2-efficiency.

	(1)	(2)	(3)	(4)	(5)
ln emissions efficiency (t-1)	0.647	0.591	0.755	0.753	0.676
	(6.94)**	(6.69)**	(8.20)**	(6.85)**	(6.30)**
Machinery and manuf. import	0.186				0.200
weighted spatial lag (t-1)	(2.91)**				(2.43)*
Machinery and manuf. export		0.055			-0.069
weighted spatial lag (t-1)		(1.61)			(0.92)
FDI stock stock			0.023		-0.009
weighted spatial lag (t-1)			(0.85)		(0.33)
Telecommunication				-0.036	-0.039
weighted spatial lag (t-1)				(1.18)	(1.43)
ln GDP p.c.	0.258	0.398	0.166	0.010	0.390
	(2.60)**	(3.65)**	(2.95)**	(0.10)	(5.00)**
% Industry value added	-0.006	-0.010	-0.005	-0.009	-0.006
	(1.85)	(3.04)**	(2.65)**	(2.28)*	(2.62)**
Observations	1012	980	1271	1269	767
Countries	83	83	90	92	78
Test of no second-order auto-	0.708	-0.732	1.156	1.203	-1.611
correlation (p-value in brackets)	(0.479)	(0.464)	(0.248)	(0.229)	(0.107)

Arellano and Bond (1991) GMM estimation. Coefficients of year-specific time dummies and constant not reported. Dependent variable is ln emissions-efficiency. Absolute robust z-statistics in parentheses. * significant at 5%; ** significant at 1% level.