TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY
ISSN 2029-4913 / eISSN 2029-4921

2017 Volume 23(2): 316–338
doi:10.3846/20294913.2015.1072752

THE INTERNATIONAL STRENGTHENING OF IPR AND AIR POLLUTION ABATEMENT: THE ROLE OF THE TRIPS AGREEMENT

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Received 18 July 2012; accepted 17 June 2014

Abstract. This paper comes in the wake of the literature considering technological progress as the main device to offset air pollution caused by economic activity. The issue has been extensively studied in general, but there is no previous research on the effects that an international strengthening of legal protection of Intellectual Property Rights (IPR) due to the Uruguay Round Agreement and the Annex on Trade-Related aspects of the IPR (TRIPs, for short), underwritten in 1994, may have had on worldwide emissions, as a result of the discovery of new or more efficient air pollution abatement technologies. Different econometric models are used to give a quantitative measure of the TRIPs agreement to reduce air pollution. In particular, the impact of the TRIPs is addressed using a dummy variable and the index of Ginarte and Park (Ginarte, Park 1997) that is one of the more commonly used indicators of TRIPs enforcement employed in economic literature. The findings of this research partially support the idea that the strengthening of a uniform minimum standard protection level of IPR, among the member countries of the World Trade Organization, may help to reduce air pollution emissions.

Keywords: air pollution emissions, environmental protection, intellectual property rights (IPR), North-South trade, TRIPs agreement.

JEL Classification: O33; Q56.

Introduction

The aim of this paper is to evaluate the spill-over on air pollution emission levels of the international agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs for short). The TRIPs constitutes Annex 1 C of the Uruguay Round Agreement establishing the World Trade Organization (WTO), signed in Marrakesh (Morocco) on 15 April 1994,

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among the member nations of the created WTO, to strengthen the Intellectual Property Rights (IPR) and raise the common minimum level of protection of innovation[1].

Since the seminal paper of Stiglitz (1974) technological progress has been viewed as the main device to offset the air pollution due to economic activity. An international increase in IPR legal protection acts directly to spur technological progress (Helpman 1993) and indirectly to encourage more environmental friendly production processes (OECD 2011). This means that although technological progress has a positive spillover on air pollution abatement, from the point of view of economic policy measures the incentives to innovate in general, must be distinguished from the incentives to improve air pollution abatement technologies, if this is the specific goal pursued by policy makers[2].

The problem is that to promote technological progress, society should permit an inventor to reap the benefit of her/his discovery for a limited time, after which period of monopoly all society should benefit from the technological advancement (Arrow 1962). Such a regime of patents implies that, during the period of exclusive ownership of an innovation, consumers have to pay monopolistic prices that may be too high for less wealthy nations (Gopakumar 2010; Lo 2011; Nain 2006).

This is the reason why poor countries, before 1995, were unable to ensure full protection to intellectual property rights (IPR). The burden to satisfy current needs forced them to forego opportunities for future development (Sonderholm 2010; Grossman, Lai 2004), it constituted not only a hurdle for the international transfer of technology, from North to South of the world, but also an impediment to domestic innovations in countries where the IPR are not fully protected (Branstetter 2004). The insufficient level of technological progress generated in developing countries may help to explain why the pollution emissions that are registered there are, without environmental policy implementations, beyond sustainable levels (Tamazian *et al.* 2009; Dechezleprêtre *et al.* 2013).

Until 1994, while all the wealthy countries were in favour of a stronger protection of innovation, developing economies deserve some attention; they were against extensive IPR patronage, arguing that this kind of policy merely transfers rent to multinational enterprises, leading neither to development for the less wealthy nations, nor to growth for the world as a whole (Dinopoulos, Segerstrom 2010).

The TRIPs agreement underwritten by the member nations of the WTO on Trade-Related Aspects of IPR, which became operative on 1st January 1995, constitutes a point of equilibrium between the conflicting interest of wealthy and developing countries, allowing five years to developing countries to acknowledge the TRIPs agreement in their domestic legal systems, while the extremely underdeveloped countries have an additional term of six years to implement this agreement (Reichman 2000). Developing countries are granted a longer period of time to implement the TRIPs agreement, so that they have enough time to

[1] The other Annexes of Uruguay Round Agreements are: 1A Multilateral Agreements on Trade in Goods (that include the revision of General Agreement on Tariffs and Trade (so called GATT 1994); 1B General Agreement on Trade in Services (GATS); 2. Dispute Settlement Understanding; 3. Trade Policy Review Mechanism; 4. Plurilateral Trade Agreements.

[2] The spillover of the TRIPs agreement on air pollution is considered ignoring the other potential effects of the Uruguay Round agreement, because they are more difficult to consider in an empirical analysis.

can make structural changes in their economic systems to render effective a strengthening of IPR legal protection, compatible with their current and future per capita income.

The TRIPS Agreement may be considered a step forward compared to previous treaties on IPR,[3] because its ratification was a mandatory condition to become a member of the WTO. Each nation attempting to obtain access to international markets opened by the WTO must embody the strict intellectual property laws established by the TRIPS Agreement. This is the reason why the TRIPS Agreement is the most important multilateral instrument for the globalization of IPR laws. Developing countries like Brazil, China and India were forced to implement the requirements of the TRIPS in their legal systems, to became members of the WTO. Since 1995 patent application by residents has risen significantly.

Very few theoretical papers in economic literature investigate the effects of the TRIPs agreement on pollution, air emissions abatement and biological diversity (Chang, Ross 2009; Coban 2004; Droege, Soete 2001; Swanson, Göschel 2000), although the discovery and diffusion of technologies is crucial for the achievement of environmentally sustainable patterns (Dechezleprêtre *et al.* 2013). The interesting contribution of Littleton (2009) constitutes a remarkable exception, but although it deals with TRIPs it does not perform a qualitative analysis, but focalises more on the legal aspects of this agreement and its spillover on climate change.

Applied research on the consequences of technology transfers from North to South of the world have overlooked the effects on environmental friendly process implementation (Bessen, Maskin 2009; Boring 2015; Branstetter *et al.* 2011, 2006; Chen, Puttitanum 2005; Evenson, Kumar 2003; Seo *et al.* 2015; Hübler 2011; Ivus 2010; Lai 1998; Lerner 2002; McCalman 2005; Sakakibara, Branstetter 2001; Scherer, Weisburst 1995; Yang, Kuo 2008; Žigic 1998)[4], with few notable exceptions (Dechezleprêtre *et al.* 2013; Dekker *et al.* 2012; Lovely, Popp 2011; Wang *et al.* 2012). This little stream of literature found a strong and significant positive correlation between technological progress and pollution reduction. Within this recent and interesting branch of research, however, none of the studies deal with the effects of the TRIPs agreement on air pollution emissions. Although this agreement is not directly aimed to reduce emissions and improve the quality of the environment, as in the case of the Helsinki and Olso protocols signed in 1985 and 1994 respectively (Dekker *et al.* 2012), but wishes to raise the level of the common minimum standard in IPR legal protection (among member countries of the WTO), nevertheless it constitutes the substrate to further innovations of more environmental friendly technologies, through the channels of international transfer of technologies and domestic innovation, spurred by TRIPs implementation.

In the economies with lower protection of IPR it is cheaper to imitate foreign innovation than to perform domestic R&D. Introducing a strengthening of IPR legal protec-

[3] There are many important treaties on IPR protection like, for example, the Paris convention for the Protection of Intellectual Industrial Property of 1883 as modified in 1979, the Patent Cooperation Treaty of 1970 and the Strasbourg Agreement concerning the International Patent classification of 1971.

[4] For a survey of this literature see Keller (2004). For a review of the studies regarding the effects of strengthening the IPRs on trade, FDI and other channels of technology diffusion, see Falvey and Foster (2005).

tion among all member countries of the WTO, in addition to promoting the international transfer of technology, have the effect of spurring domestic innovation and discouraging the process of imitation (Helpman 1993).

Following the results of previous theoretical models, it is expected that the implementation of the TRIPs agreement will favour, the international transfer of technologies and domestic innovation at the same time, as a result of the appropriability of the revenues (royalties) deriving from patents, which may lead to the discovery and implementation of technologies that will help to reduce the levels of emissions in the atmosphere (in particular we consider CO2 and PM10, that notoriously possess different dynamics (Di Vita 2008).

The present research attempts to answer the following questions: a) has the TRIPs agreement contributed to reduce air pollution levels (CO2 and PM10)?; b) which would be more effective to abate air pollution, domestic innovation (measured by patent applications by residents), or technology transfer or diffusion (due to FDI); c) which pollutants have been reduced through technological change and which have not? These three questions are important because there is no economic research on this topic, thus the attempt of this study is to take one step further with respect to existing literature.

To provide an answer to the questions above, some regressions were performed using different models, for the purposes of comparison. The models used were the random effects (RE), and dynamic panel data analysis, following the Arellano-Bover approach (Baltagi 2008).

A total of thirty-eight countries are considered of which twenty-one developed and the remaining developing. Our dataset covered a period of twenty-one years, from 1986 to 2006, using economic data derived from the World Development Indicator (WDI) (World Bank 2013).

Two different indicators of air pollution were alternatively considered as dependent variables: carbon dioxide emissions (CO_2), produced by the burning of fossil fuels and the manufacture of cement, and particulate matter concentrations, referred to the fine suspended particles of less than ten microns in diameter (PM10)[5]. These two sources of pollution have been extensively used in previous studies on the relationship between per capita income and pollution (so called: Environmental Kuznets Curve (EKC). See Kijima *et al.* 2010; Panayotou 2000). Aware of the recent criticisms of the EKC (Stern 2004), the analysis has been extended by the explicit inclusion of some new covariates. For example we take into account the Kyoto Protocol signed in 1997 and brought into force in 2005 to reduce global warming. Moreover, fuel prices are considered among the regressors because they reflect the technologies implemented to reduce air pollution. Finally, an indicator of the measures of economic policy adopted at a national level to reduce atmospheric pollution will be considered in the analysis.

To give a quantitative measure of the TRIPs agreement to reduce air pollution, we use a dummy variable in the econometric analysis as well as the index of Ginarte and Park (Ginarte, Park 1997; Park 2008) that is one of the commonly used indicators of TRIPs enforcement employed in economic literature.

[5] To account for air pollution it is also possible to use PM2.5 (Particulate air matter with a diameter of less than 2.5 micrometers), but the use of this variable in this research was constrained by the unavailability of data for all the countries considered.

We found some evidence that the uniform minimum standard protection level of IPR, among the members of the WTO, due to the TRIPs agreement, is helpful to cut down air pollution emissions, through the implementation of more sustainable technologies.

The structure of the paper is as follows. After this introduction, Section 1 is dedicated to describing the theoretical background. Section 2 is devoted to the analysis of data and preliminary statistics. Section 3 regards the econometric analysis. Final remarks conclude the paper.

1.Theoretical background

To evaluate the impact of the TRIPs agreement on air pollution, it is first necessary to explain from which theoretical assumptions we move.

1.1. International trade, foreign direct investment, patents applications and the TRIPs agreement

In his seminal paper Helpman (1993) observes that while in the wealthy market economies patent, trademark, and copyright laws prevent the violation of IPR, nevertheless legal protection in those countries is far from perfect, imitation is widespread, and often important information leaks out already during the development process. This may contribute to explain why for many years the developing countries have refused to sign international agreements concerning the protection of intellectual property rights, and others have laxly enforced domestic laws and regulations designed for this purpose (Helpman 1993). The international trade models accounting for the effects of an increase of the IPR legal protection on technological transfers from North to South of the world have detected two main channels, by means of which a stronger protection of the IPR might encourage technological progress: a) international trade (trade); b) foreign direct investment (fdi) (Anyangah 2010; Glass, Wu 2007; Glass, Saggi 2002)[6]. Moreover increasing the degree of legal protection of IPR has the effect of stimulating patent application by residents (par) (Allred, Park 2007; Branstetter *et al.* 2006; Parello 2008). The increase in patent applications, after 1995, due to the TRIPs agreement is well documented in economic literature (Di Vita 2013). But the rise in R&D and technology transfer had already been stimulated in '90 by WIPO's (World Intellectual Property Organization) system strengthening, due to the Uruguay Round Agreement signed on 15 April 1994.

International trade is an indirect mechanism of technological transfer, because the tighter IPR legal protection changes the terms of exchange among countries (Helpman 1993). The commerce of patented products, or those commercialized under trademarks, as well as those produced with copyright protection (for example, software, pharmaceuticals, videos, etc.), is fostered under a high level of IPR legal protection.

[6] There are other channels for technology diffusion in addition to FDI and trade, like licensing, migration (temporary or permanent), attendance at conferences, internet use, etc, etc., not all of them are easy to measure however (see Smith 2001).

Foreign direct investment (fdi) is a direct channel of international transmission of technologies among countries (Keller 2004). The investment of international firms fosters worldwide technological spillovers, because multinationals "supply a 'package' of needed resources including management experience, entrepreneurial abilities, and technology skills which can then be transferred to their local counterparts by means of training programs and the process of 'learning by doing'" (Todaro, Smith 2009). Finally, the patent applications by residents represent a direct measure of the effects of tighter IPR protection within countries, because the innovators of goods or productive processes, under a regime of full IPR protection, face fewer difficulties in appropriating the fruits of their labour (Helpman 1993). In other words the appropriability of the revenue of the innovation stimulates the domestic activity of R&D, reducing the dimension of the area of imitation.

Under prior assumptions we may assume that international trade and foreign direct investments are complementary to each other, while both of them are alternative to domestic activity in R&D.

In Helpman's analysis (1993) international agreements are considered the principal measure to promote domestic innovation and international transfer of technology at the same time, reducing the imitation process.

1.2. Innovations, air pollution emissions and income

These three sources of technological innovation constitute a prerequisite to prompt the discovery of channels by means of which a higher IPR protection may be useful to reduce air pollutant emissions. Lanjouw and Ashoka (1996) demonstrate that in the second half of the last century a considerable increase of knowledge at world level corresponds to a rise in environmental patenting. They report that in the United States, Japan and Germany, over the 1970s and 1980s, the ratio of environmental patents to all the patents varied between 0.6 and 3%, becoming greater than the corresponding percentage of pollution abatement expenditure in GDP. Even in developing countries the environmental patenting rates were high, reaching 2% of the total of patents in Brazil. Most of the environmental innovations were obtained, in a non negligible amount, to adapt imported technologies to local conditions. However, in developing countries domestic patenting provides only one path to new technologies, because they attract foreign investment with their disembodied environmental technologies (in East Asia technologies integrated in pollution abatement equipment are often employed).

Since the seminal paper of Grossman and Krueger (1991) who first studied the connection between air pollution and income, the inverse U-shape of this relationship has been demonstrated (Dinda 2004), despite the recent critics on EKC (Stern 2004).

The most used indicators of air pollution are carbon dioxide emissions (CO_2) produced by the burning of fossil fuels and the manufacture of cement, and particulate matter concentrations, referred to the fine suspended particles of less than ten microns in diameter (PM10), that are capable of penetrating deep into the respiratory tract and causing significant health damage. The first pollutant regards prevalently the welfare of future generations, while particulate matter strongly affects the well-being of living people. In the presence of intergenerational externality, because nobody is entitled to bargain for future generations, devices will be implemented and economic policy measures adopted to improve the welfare of the current generation. Previous analyses underlined the non-linear dynamics between air pollution and income (Andreoni, Levinson 2001). Moreover, each air pollutant follows a different path in consideration of a different level of per capita income (Dinda 2004; Di Vita 2008; Panayotou 2000).

1.3. National dimension environmental policies

Recently, to study the air pollution abatement policies, some emphasis has been placed on the stringency of national policies (OECD 2011), adopted in accordance with the application of important international agreements to protect the environment, like the Kyoto Protocol (Chen, Wang 2012). Some indicators of environmental sustainability behaviour at a national level have been elaborated, to account for the effectiveness of the pollution abatement policies adopted (Esty *et al.* 2005).

An indirect indicator of domestic policy for air pollution reduction is the variation in fuel prices, that might drive investments in energy efficiency technologies with an ancillary benefit of reduced CO2 emissions. Worldwide CO2 regulations are a relatively recent phenomena and fossil fuel prices, on the other hand, are also a major driver of CO2 emissions reduction as they encourage investments in energy efficiency (Śmiech, Papież 2013).

2. Data analysis and preliminary statistics

This study takes into consideration the data regarding thirty-eight countries, chosen on the basis of the constraint represented by availability of data concerning patent applications jointly with other figures required for this research[7]. Twenty-one wealthy countries and seventeen developing economies are accounted for. The latter are classified according to their per capita income, lower than or equal to 10,725 US $, defined at 2000 current prices[8]. The full description of the countries considered is reported in Table 1.

Table 1. Classification of countries according to per capita income level

Wealthy countries (a)	Developing countries (b)
Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hong Kong, Ireland, Israel, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, United States.	Argentina, Brazil, Chile, China, Colombia, India, Indonesia, Korea Republic, Malaysia, Mexico, Pakistan, Peru, Philippines, Portugal, Turkey, Uruguay, Venezuela.

Note: Column (a) lists the twenty-one developed countries with a per capita income greater than 10,725 US $ (measured at 2000, expressed in US $ current prices in that year), while column (b) lists the seventeen developing countries with a lower per capita income level.

[7] There are countries for which the patent application by residents data are available, but other figures used in this paper no, so our choice of the countries to consider was constrained by availability of complete data.

[8] The world Bank classifies countries, based on their per capita income, in three groups: i) developing, with a per capita income between, $0 – $3,465; ii) medium, with a per capita income in the range between $3,466 – $10,725; iii) industrialized countries with a per capita income of $10,726 or more. For the limited purposes of this paper, and due to the scant availability of data regarding patent applications of residents and non-residents in the period considered, we decided to incorporate the first two groups of economies into one that we call developing countries with a per capita income from zero to 10,725 US$ at 2000 prices.

The variables considered in the econometric analysis, their full description and sources are reported in Table 2.

Table 2. Variables and data sources

	Type of Variable	Description and source
(1)	Patent applications by residents (par)	Patent applications by residents. Source: World Intellectual Property Organization (WIPO), World Intellectual Property Indicators and www.wipo.int/econ_stat (WIPO 2013), reported in World development indicator (2013).
(2)	CO2 emissions (co2)	CO2 emissions (metric tons per capita). Source: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, U.S. state of Tennessee (CDIAC 2013), in World development indicator (2013).
(3)	PM10, national level (pm10)	PM10, national level (micrograms per cubic meter). Source: Kiren Dev Pandey, David Wheeler, Bart Ostro, Uwe Deichmann, Kirk Hamilton, and Katherine Bolt. "Ambient Particulate Matter Concentrations in Residential and Pollution Hotspot Areas of World Cities: New Estimates Based on the Global Model of Ambient Particulates (GMAPS)", World Bank, Development Research Group and Environment Department (Pandey *et al.* 2006) in World development indicator (2013).
(4)	Foreign direct investment (fdi)	Foreign direct investment, net inflows (% of GDP). Source: International Monetary Fund,International Financial Statistics and Balance of Payments databases, World Bank, Global Development Finance, and World Bank and OECD GDP estimates, in World development indicator (2013).
(5)	GDP per capita (gdppc)	Gross Domestic Product per capita (constant 2000 US$). Source: World Bank, International Comparison Program database in World development indicator (2013).
(6)	International trade (trade)	International trade (% of GDP). Source: World Bank national accounts data, and OECD National Accounts data files World development indicator (2013).
(7)	TRIPS dummy (tripsdummy)	This is a dummy variable that assumes the value of 0 from 1986 to 1994, before the Trips agreement came into force. From 1995 it takes the value of 1.
(8)	Index of patent protection (parkindex)	This index was built using the data provided by Ginarte and Park (1997) and updated by Park (2008), that account for patent protection using the simple sum of five separate scores for: coverage (inventions that are patentable); membership in international treaties; duration of protection; enforcement mechanisms; and restrictions. In particular to undertake the changes in IPR strengthen the differences between the values of average observation for the period 1960–1990 and the values for 2005 was calculated. Sources: Ginarte and Park (1997) and Park (2008).
(9)	Legal family dummy (dumlex)	This is a dummy variable (dumlex) that takes the value of zero in economies with civil law legal system, and one for countries with a common law legal system. Source: La Porta *et al.* (1998).
(10)	Kyoto Protocol dummy (kyoto)	It is a dummy variable (kyoto) that takes the value of zero if the countries did not ratified the Kyoto protocol by December 2002, and one for nations that have ratified this international agreement within this data. Source: United Nations (2013) at: http://unfccc.int/kyoto_protocol/items/2830.php.

End of Table 2

	Type of Variable	Description and source
(11)	Fuel price index for country (fpic)	Pump price for diesel fuel (US$ per liter) refer to the pump prices of the most widely sold grade of diesel fuel. Prices have been converted from the local currency to U.S. dollars. Source: World development indicator (2013).
(12)	Environmental sustainability index (esi)	This is an index (esi) measuring the capability of nations to protect the environment in the future. It may assume values from 10 for countries with a strong environmental sustainability behaviour, and 0 in economies with an environmental unsustainable growth path. This index is built using 76 data sets, regarding several environmental indicators of environmental sustainability. For a more detailed description of this index see Esty *et al.* (2005).

Notes: This table describes the variables considered for the thirty-eight countries included in our study, their definitions and sources.

Two different indicators of pollution are considered: carbon dioxide emissions (CO_2) and particulate matter (PM10), that are the most commonly used in applied analyses of the relationship between per capita income and air pollutant (Dinda 2004; Panayotou 2000). Admitting that both air pollutants possess inverse U-shaped dynamics, CO2 shows its peak in correspondence with a much higher per capita income level than particulate matter. This means that the current generation is predicted to be more willing to devote resources to reducing the kind of pollution that more directly influences its welfare, especially in developing countries that have an inter-temporal budget constraint represented by the necessity to satisfy present needs.

Patent applications by residents (par) were included among the covariates to consider the effects of the strengthening of IPR legal protection at an international level, due to the TRIPs agreement, in stimulating domestic innovation. This channel of technological improvement in general constitutes a condition for the discovery and implementation of sequential innovation to air pollution emissions abatement. The par variable was assumed *ex ante* to be helpful in reducing pollution in general, with a difference in effects between wealthy economies and developing countries. Regarding foreign direct investment (fdi) also, our prediction, based on international trade models, is that this variable may contribute to air emissions abatement.

Following the literature on the relationship between per capita income and pollution (the so called Environmental Kuznets Curve, EKC) (Dinda 2004; Kijima *et al.* 2010; Panayotou 2000), the gross domestic product per capita (gdppc) was considered among the covariates. Previous theoretical and empirical analysis on the EKC suggests an inverse ratio between per capita income and emissions, with different effects for wealthy and developing countries. The nonlinear dynamics of both pollutants suggest including among the regressors also the square of gdppc (squaregdppc).

International trade was included among the covariates to explain the emission levels, following the existent studies on this issue, which have found the effects of cross-border commerce on the environment to be positive (Antweiler *et al.* 2001).

To consider the effects of the TRIPs agreement on the indicators of the air pollution level, we consider among the regressors, alternatively, a dummy variable assuming the value of zero for the years from 1986 to 1994, prior to the agreement come into force, and the value of one for the rest of the period until 2006 (tripsdummy), and an indicator built on the index established by Ginarte and Park (1997) and recently updated by Park (2008). The index is the unweighted sum of five separate indicators; the coverage related to the kind of innovations that are patentable; the membership of the country considered in international treaties[9]; the protection of patents during time; the enforcement mechanisms adopted in each country; the mandatory licensing in the hypothesis that a patented invention is not sufficiently exploited or for prevailing public interests (Ginarte, Park 1997; Park 2008). In particular in this paper, for the purposes of comparison of regressions results gained using the dummy variable that accounts for the effects of the TRIPs agreement, we use the differences in the Ginarte-Park index for the period 1960–1990 (average) and those made available for 2005 (parkindex), because we want to measure in a more direct way the strengthening of IPR prior to and after the TRIPs agreement coming into force. In consideration of the five indicators employed the parkindex constitutes a more precise way to account for the strengthening of the IPR and the effort made in each country towards this aim from 1990 to 2005, with respect to the simple introduction of a dummy variable. The Ginarte and Park index is one of the commonly used indicators of TRIPs enforcement employed in economic literature: it may assume values between zero and five, where zero is the worst result with no protection of IPR within the country considered (Ginarte, Park 1997; Park 2008).

To avoid potential distortion in the estimated regressors a time invariant dummy variable (dumlex) was included among the covariates. It assumes the value zero in economies where the legal system belongs to the civil family, and one for countries with a common law legal system, following the classification of La Porta *et al.* (1998). Differences in legal systems influence the enforcement of law (La Porta *et al.* 1998), and the legal family of an economy is relevant for income and trade because to exchange goods and services across national borders, buyers and sellers enter into international sales contracts.

The number of countries considered makes it impossible to say anything about the dynamics of the variables. The different stages of growth of each country is obviously reflected in its data, but in the panel data analysis the time trend is inevitably overlooked.

To evaluate the impact of the international constraint on the domestic policies to reduce emissions, a dummy variable accounting for the Kyoto protocol (Kyoto) is considered. This international agreement was signed in December 1997 under the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan, and came into force on 16 February 2005 (Chen, Wang 2013). The Kyoto Protocol was the first agreement in the world to formally address climate change by mitigating the effects of Greenhouse Gas Emissions (for short GHG).

The ratification of the Protocol expresses the will of the countries to introduce measures and regulations, within their domestic borders, to reduce air pollution emissions. Among the wealthy countries, as reported in Table 1, Australia, Hong Kong, Switzerland and United States did not ratify the Kyoto protocol by December 2002, while five developing countries (Indonesia, Pakistan, Philippines, Turkey and Venezuela) among those included in our panel, have not signed this international agreement. To assess the effects of this international agreement we consider a dummy variable (kyoto) that takes the value of zero if the countries did not ratify the Kyoto protocol by December 2002, and one for

[9] The index of IPR protection by Ginarte and Park (1997) explicitly accounts for the effects of treaties on IPR legal protection signed before 1994. For a recent application of Ginarte and Park index to pharmaceutical inventions, see Liu and La Croix (2015).

nations that ratified this international agreement within this date[10]. *Ex ante* we expect to find a negative relationship between this dummy and both air pollutants,

Among covariates the fuel price index for country (fpic) is also included to control for the indirect effects of R&D expenses to reduce fossil fuels consumption (Śmiech, Papież 2013) to reduce CO2 and PM10 emissions. Fossil fuel prices are one of the most important determinants of CO2 emissions abatement, via reduction of fossil fuel demand, and they also spur investment in gasoline saving technologies. The data of this index are not available for all the years in the period considered, so the results of regression where this covariate is used should be evaluated carefully. In consideration of the negative correlation between price and demand of carbon fuel, we assume that there is a negative correlation between this regressor and both indicators of air pollution.

Finally, to complete the analysis of the stringency of national policies to reduce air pollution, the environmental sustainability index (esi) (Esty *et al.* 2005) is also included among the covariates. This index supplies a measure of environmental sustainability that is a multi-dimensional concept, in terms of countries' capability to protect the environment. The higher a country's ESI score, the better positioned it is to maintain favourable environmental conditions in the future (Esty *et al.* 2005). This index may assume values between 10 in the most virtuous countries and zero in countries with an unsustainable environmental behaviour. In consideration of the environmental sustainability index an inverse relationship is forecast between ESI and both indicators of air pollution.

After the description of the variables considered in the analysis and some comments about them, the preliminary statistics are reported in Table 3, and the correlation matrix in Table 4[11].

Table 3. Summary of statistics

	Variables	Obs.	Mean	S.D.	Min.	Max
(1)	Patent applications by residents (par)	798	17558.63	58994.41	9	38420.1
(2)	CO2 emissions (co2)	798	6.8909	4.6232	0.054	21.11
(3)	PM10, national level (pm10)	798	48.7463	52.7722	0.963	111.84
(4)	Foreign direct investment (fdi)	798	2.5272	4.9106	–15.13	91.67
(5)	GDP per capita (gdppc)	798	14607.42	10668.62	271	41441
(6)	International trade (trade)	798	68.5599	50.7567	12.36	399.53
(7)	TRIPS dummy (tripsdummy)	798	0.5714	0.4952	0	1
(8)	Index of patent protection (parkindex)	798	1.9079	.575688	0.74	2.90
(9)	Legal family dummy (dumlex)	798	0.2895	0.4538	0	1
(10)	Kyoto Protocol dummy (kyoto)	798	0.7619	0.4262	0	1
(11)	Fuel price index for country (fpic)	798	0.6774	0.3799	0.01	1.73
(12)	Environmental sustainability index (esi)	798	54.5605	9.4771	38.6	75.1

[10] In consideration of its economic relevance at world level it is worth pointing out that China became a member of the WTO in 2001, in the same year the TRIPs agreement adoption became compliance for this country (Tormans *et al.* 2007).

[11] To test the poolability of the panel data the Chow test was adopted. It was possible to calculate the F statistic to check the poolability of data across countries, F^c_{obs}, with five degrees of freedom, like the number of covariates, and thirty-eight countries considered and twenty-one observations for each country. The result is $F^c_{obs} = 169.02$, that is lower than the F-value of 228.16 obtained for $F(37,755)$ such that the null hypothesis is not rejected.

Table 4 Correlation matrix table

	Variables	(1) par	(2) co2	(3) pm10	(4) fdi	(5) gdppc	(6) trade	(7) tripsdummy	(8) parkindex	(9) Dumlex	(10) Kyoto	(11) Fpic	(12) esi
(1)	Patent applications by residents (par)	1											
(2)	CO2 emissions (co2)	−0.2667	1										
(3)	PM10, national level (pm10)	−0.0762	−0.403	1									
(4)	Foreign direct investment (fdi)	−0.1026	0.480	−0.0847	1								
(5)	GDP per capita (gdppc)	0.3979	0.7150	−0.3653	0.0877	1							
(6)	International trade (trade)	−0.2090	0.0383	−0.0273	0.3050	0.1959	1						
(7)	TRIPS dummy (tripsdummy)	0.0528	0.0893	−0.0828	0.2064	0.1430	0.1366	1					
(8)	Index of patent protection (parkindex)	−0.1889	−0.6067	0.2815	−0.0782	−0.7207	−0.2365	0	1				
(9)	Legal family dummy (dumlex)	−0.0022	0.3415	−0.0349	0.0477	0.0611	0.2656	0	−0.16	1			
(10)	Kyoto Protocol dummy (kyoto)	−0.0041	−0.0367	−0.1145	0.0480	0.0107	−0.1404	0.0282	0.0849	−0.1804	1		
(11)	Fuel price index for country (fpic)	0.0375	0.3080	−0.2211	0.0832	0.6527	0.1776	0.2529	−0.3865	−0.1283	0.2384	1	
(12)	Environmental sustainability index (esi)	−0.0429	0.1939	−0.0800	−0.0501	0.3413	−0.2220	0.0568	−0.0659	−0.2885	0.3537	0.2669	1

The coefficient reported in the matrix of correlation confirms that CO2 and PM10 are negatively correlated, this suggests that we should expect different results for these two air pollutants. Moreover we may observe that international trade and foreign direct investments are complementary because we find a positive correlation, while both are alternative to domestic activity in R&D, as proved by the fact that their coefficients possess a negative algebraic sign.

3. Econometric analysis

The econometric model that satisfies the above theoretical analysis is

$$\begin{aligned} \mathrm{CO2}_{j,t} &= \alpha_1 \mathrm{const} + \alpha_2 \mathrm{tripsdummy}_{j,t} + \alpha_3 \mathrm{par}_{j,t} + \alpha_4 \mathrm{trade}_{j,t} + \alpha_5 \mathrm{fdi}_{j,t} + \alpha_6 \mathrm{gdppc}_{j,t} + \\ &\alpha_7 (\mathrm{gdppc})^2{}_{j,t} + \alpha_8 \mathrm{dummylex}_j + u_t , \end{aligned} \quad (1)$$

where: const – is the intercept term; u_t – is a stochastic term. When the Arellano-Bover (GMM) model is used (Baltagi 2008), it will assume the form $u_{vj,t} = \mu_v + v_{jt}$, where μ_v represents the autocorrelation due to the presence of lagged dependent variables among the regressors, and v_{jt} the individual effects characterizing heterogeneity among nations; α_i are the coefficients of regressors ($i = 1, \ldots, 9$).

$j = 1, \ldots, 38$, denotes the thirty-eight countries considered and $t = 1, \ldots, 21$, is the period of observation (from 1986 to 2006). Moreover other regressions were performed using PM10, instead of CO2, as an indicator of pollution emissions, employing the same econometric model. The second addend in [1] is the lagged dependent variable. Using the same specification the regressions are also run using the parkindex instead of tripsdummy, to check for the effects of a strengthening of IPR protection, and making a comparison with the results obtained in the regressions using the dummy representative of TRIPs implementation.

The regressions were made using Random Effects (RE)[12] and Arellano-Bover (GMM) models[13]. We choose to run the regressions with these two econometric models, because RE accounts for the panel dimension of our sample and Arellano-Bover allows us to capture the dynamics of the variables considered[14].

The regressions were also performed for both pollutants, employing the observations for wealthy and developing countries separately, to better understand the relationship between air pollution levels and technological progress, in countries at different stage of development.

The results of the regression are reported in Tables 5 and 6.

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[12] The random effect model is able to account for a possible selection bias effect due to the countries selected and included in the sample (Verbeek 2012). The strong similarities in the outcome of regressions performed with OLS and RE exclude the existence of selection bias.

[13] The GMM method is one step and the instrument is the dumlex. The Arellano-Bover econometric model (GMM) assumes that the lagged dependent variable of at least one period should be included among the regressors, to consider the dynamics of the phenomenon to be studied. See Greene (2008).

[14] The results of regressions, considering the entire panel of countries, performed using the models of OLS and random effects, taking the natural logs of variables (log model), are available upon request from the author.

Table 5. Results of regressions using CO2 as dependent variable, for rich and developing countries separately

	(I) RE				(II) GMM			
	(developing)		(rich)		(developing)		(rich)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Covariates								
Constant term	811.41 (6.06)***	727.95 (2.48)**	−85.48 (−1.57)*	−77.842 (−1.57)*	400.58 (4.69)***	371.76 (3.02)***	−1.908 (−0.13)	−106.645 (−2.20)**
CO2 (Lag one year)					0.7152 (17.59)***	0.7291 (17.85)***	.8274 (17.66)***	0.8208 (17.64)***
Dummy ccounting for TRIPS agreement (tripsdummy)	23.887 (1.44)		−6.943 (−1.35)		14.72 (1.67)*		−7.617 (−1.71)*	
Index of patent protection (parkindex)		0.0497 (0.13)		0.00288 (0.03)		−0.1646 (−0.42)		0.4071 (2.26)*
Patent applications by residents (par)	−0.0015 (−3.14)***	−0.0014 (−2.91)***	0.0011 (4.20)***	0.0011 (4.21)***	−0.0014 (−5.70)***	−0.0013 (−5.46)***	0.0003 (1.44)	−0.0003 (1.32)
International trade (trade)	−0.0231 (−4.95)***	−0.0229 (−4.89)***	−0.009 (4.76)***	−0.0083 (4.52)***	−0.0093 (−4.12)***	−0.0094 (−4.02)***	−0.0028 (1.68)*	−0.0027 (1.70)*
Foreign direct investment (fdi)	−0.0044 (−.45)	−0.0032 (−0.33)	−0.0254 (−1.86)*	−0.0281 (−2.06)**	−0.0128 (−2.33)**	−0.0112 (−2.06)**	−0.0003 (−0.03)	−0.0073 (−0.65)
GDP per capita (gdppc)	−0.007 (−0.81)	−0.0023 (−0.29)	−0.0023 (−0.29)	−0.0955 (11.57)***	−0.0935 (11.38)***	−0.179 (−2.83)**	0.010158 (1.76)*	−0.0221 (2.96)**
Gdppc^2 (squaregdppc)	6.51e−07 (4.04)***	6.10e−07 (3.83)***	−2.53e06 (5.76)***	−2.48e−06 (−5.65)***	6.31e07 (5.07)***	5.71e07 (4.54)***	−5.55e07 (−1.67)*	−1.10e−06 (−2.88)
Legal family dummy (dumlex)	495.29 (3.59)***	498.34 (3.44)***	117.95 (1.46)	119.01 (1.48)*	119.69 (4.11)***	117.58 (3.73)***	26.513 (1.17)	47.403 (2.16)*
R-squared♣: overall within between	 0.4272 0.2830 0.4434	 0.4185 0.2781 0.4403	 0.7188 0.7181 0.7216	 0.7191 0.7162 0.7252				
Observations	440	440	358	358	440	440	358	358

Note: T-values in parentheses. ***, **, * – indicate statistical significance at the 1%, 5%, and 10% level respectively; ♣ – in case of OLS only the values of R-squared is reported.

Table 6. Results of regressions using PM10 as dependent variable, for rich and developing countries separately

	(I) RE				(II) GMM			
	(developing)		(rich)		(developing)		(rich)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Covariates								
Constant term	5214.484 (10.00)***	7088.06 (6.30)***	11247.26 (4.28)***	10886.91 (2.92)***	593.498 (2.35)**	1763.137 (4.87)***	11465.88 (2.85)***	−16331.09 (−1.45)
PM10 (Lag one year)					0.9055 (21.38)***	0.9318 (22.81)***	0.0211 (−0.49)	0.02105 (−0.46)
Dummy accounting for TRIPS agreement (tripsdummy)	−388.295 (−6.30)***		−362.815 (−0.54)		−70.0188 (−2.98)***		12.688 (.01)	
Index of patent protection (parkindex)		−3.3294 (−0.66)		2.218 (0.20)		−4.4846 (−3.90)***		121.6205 (2.63)***
Patent applications by residents (par)	−0.0001 (−0.41)	−0.0008 (−0.40)	−0.0001 (−0.41)	−0.0018 (−0.06)	0.0002 (0.03)	0.0002 (0.28)	0.0416 (0.83)	0.02468 (0.51)
International trade (trade)	−0.0182 (11.01)***	−.0166 (−0.88)	−0.1146 (−0.53)	−0.1506 (−0.72)	0.0189 (3.32)***	0.016146 (2.76)**	−0.8149 (−2.46)**	−0.9569 (−3.08)***
Foreign direct investment (fdi)	0.0135 (0.35)	−.0083 (−0.21)	−2.4679 (−1.53)	−2.6348 (−1.46)	0.0281 (1.88)*	0.0121 (1.32)	−3.9341 (−1.65)*	−4.9243 (−2.15)**
GDP per capita (gdppc)	−0.1125 (−3.31)***	−0.1922 (−5.83)***	−0.8475 (−1.09)	−0.8532 (−1.06)	−0.0421 (−2.11)**	−.0643 (−3.20)***	0.7810 (0.79)	2.853 (2.29)**
$Gdppc^2$ (squaregdppc)	1.26e−06 (−2.02)*	1.98e−06 (3.09)***	0.0001 (0.70)	0.0001 (0.67)	6.92e−07 (1.81)*	1.02e−06 (2.61)**	−.0001 (−1.04)	−0.0002 (−2.21)**
Legal family dummy (dumlex)	511.5473 (17.08)***	627.095 (1.14)	−1265.159 (−0.38)	−1119.93 (−0.32)	−281.7482 (−2.74)***	−356.992 (−3.46)***	−2790.244 (−0.51)	−5110.822 (−0.94)
R-squared♣: overall within between	 0.0557 0.4311 0.0255	 0.0598 0.3782 0.0380	 0.0871 0.0182 0.1728	 0.0892 0.0171 0.1784				
Observations	440	440	358	358	440	440	358	358

Note: T-values in parentheses. ***, **, * – indicate statistical significance at the 1%, 5%, and 10% level respectively; ♣ – in case of OLS only the values of R-squared is reported.

Our comments on the results of the regressions deal first with those where the dependent variable was CO_2.

Observing the value of R-squared it is immediately evident that the model explains more than forty per cent of the carbon dioxide emissions, that is a good outcome for panel data[15].

It is evident from Table 5 that the TRIPs agreement shows a negative ratio with carbon dioxide in developing economies, while the opposite is true for wealthy nations. This may be due to the asymmetric impact of this international agreement on countries at different stages of development and to the dissimilar relationship between the per capita income and CO_2 levels[16]. It is worth noting that when the Arellano-Bover model is employed, accounting for the dynamics of the variables, the dummy variable is statistically significant and at the same time possesses a negative algebraic sign in developing countries. This is consistent with the fact that the lagged dependent variable is strongly statistically significant, for both the sub-samples, because it means that the effects of stronger IPR protection are shown in the long run.

The parkindex, that is the other indicator of strengthening of IPR due, among other things, to the implementation of the TRIPs agreement, is statistically irrelevant.

Nevertheless it should be emphasized that the number of patent applications is quantitatively negligible, highly statistically significant, with asymmetric effects between developed and developing countries, when carbon dioxide emissions constitute the dependent variable. The patent applications by residents contribute to reducing the levels of CO2 in wealthy countries while they work in the opposite direction in the case of developing economies. The coefficient of this regressor in rich economies is quadruple in magnitude that in developing nations when the Arellano-Bover econometric model is used, while it is not statistically significant when different econometric model is employed.

The number of patent applications by residents has a weak relevance in explaining the observed levels of carbon dioxide and has a conflicting algebraic sign, but we may shed some light on these two variables by using the information in Table 5.

International trade is instrumental in protecting the environment and reducing pollution at a global level, but the positive effects are concentrated in wealthy economies more than in developing countries; this may be due to the fact that at the first stage of development emissions and per capita growth are positively linked. It is worth observing, from Table 5, that this regressor is always highly statistically significant when the two kinds of countries are considered separately.

Foreign direct investment contributes to reducing carbon dioxide emissions, particularly in rich countries that may benefit from per capita income increase to reduce pollution

[15] To check for possible bias in regression due to endogenity we already perform regressions using the [1] and employing the G2SLS random effects IV regression model, using as endogeneous variable the GDP per capita and as instrument the dummy accounting for legal families (dumlex). The outcome are quite similar to those reported in Tables 5 and 6. Based on this result we may exclude the distortion in regression due to endogenity (Baltagi 2008).

[16] The regression has already been run including a dummy to account for group countries, it assumes the value of 0 for developing countries and 1 otherwise. It was found that this covariate is statistically insignificant, and its impact on R2 is .0001.

by implementing environmental protection devices. Finally, the gross domestic product per capita is negatively correlated with CO2 in rich countries and positively in developing economies, and it is usually statistically significant. The square term of gdppc possesses a positive algebraic sign, although the coefficients of the regressors are low in magnitude.

In cases where PM10 is used as a dependent variable, the effects of the international agreement to protect innovation signed in 1994, using both indicators for the strengthening of IPR (tripsdummy and parkindex), always possess a negative algebraic sign and are often statistically significant. This result seems to be confirmed even in cases where regressions are run for wealthy and developing countries separately.

The dummytrips is highly statistically significant (at a level of 1 ‰) and proves to have a negative ratio with particulate emissions only in developed countries, while it is not significant for developing economies. The same results are obtained using the parkindex instead of tripsdummy. In cases where the dynamic econometric model is used, also the lagged dependent variable is strongly statistically significant. In this case too the algebraic sign of dummytrips did not change when the dynamic econometric model was used.

Residential patent applications offer a very limited explanation of the observed level of PM10 because they are not statistically significant, thus no further insights can be drawn by observing the results of regressions for the sub-samples of countries considered separately, as reported in Table 6.

For completeness of analysis we have already considered the international constraint on domestic policies to air pollution reduction introducing, among the regressors, a variable that accounts for Kyoto Protocol ratification (Kyoto). It possesses a negative algebraic sign and is highly statistically significant in cases where CO2 is the dependent variable (when OLS and RE are performed on the entire sample of countries). When we have particulate air matter on the left side of the equality sign, the kyoto dummy shows an ambiguous algebraic sign and is statistically irrelevant. It is possible to conclude that the Kyoto protocol helps to reduce air pollution emissions in the long run (Chen, Wang 2012).

Moreover, we have already included among the covariates the fuel price index for each country (fpic) to account for possible positive externality on air pollution due to investments in energy efficiency. The coefficient of this covariate possesses a negative algebraic sign and is highly statistically significant when CO2 is the dependent variable. Even using PM10 we find a negative correlation with fpic, but it is statistically irrelevant. Owing to missing data, dynamic analysis cannot be performed using this covariate. These results confirm that emissions fall when price of fuel rises (Śmiech, Papież 2013). The dummy variable accounting for legal families is statistically significant when CO2 is the dependent variable, while it is less relevant in cases where particulate air matter is considered.

Finally, to account for national stringency of pollution emissions abatement measures we run regressions enclosing the environmental sustainable index (esi) (Esty *et al.* 2005), but this covariate is always statistically insignificant[17].

[17] Even the results of these regressions are available upon request from the author.

Conclusions

The empirical analysis performed in this paper, on the effects of the TRIPs agreement on air pollution, supports the conclusions that in developed countries CO2 emissions have fallen with the number of patent applications, and PM10 emissions have fallen with TRIPS and increasing patent protection. These relationships do not hold in developing countries.

The effects of a strengthening of IPR in reducing pollution emissions are evident for particulate air matter. This result is perfectly consistent with the assumption that countries are more willing to devote resources to reducing the air pollution that more directly influences their current welfare.

The observed inconsistency of signs across regressions using CO2 and PM10 as dependent variables confirms that the two air pollutants do not have the same causal mechanisms and dynamics.

New technologies help to reduce pollution through the increase of per-capita income, foreign direct investment and international trade. The impact of international trade on emissions is greater in magnitude than that of foreign direct investment, in developing countries when the random effects econometric model is used.

It was found that foreign direct investment reduces CO2 emissions in industrialized countries, while its effects are unclear in developing economies.

Little evidence emerges that patent applications by residents may contribute, by the discovery and implementation of new technologies, to reducing pollution, because a negative relation between CO_2 and patent applications by residents was found only in developed countries.

Regarding PM10, our findings did not support the idea that within borders innovations prove useful in orienting the economic system towards more sustainable patterns. Some empirical evidence was found that foreign direct investment is a channel to promote growth and protection of the environment at the same time, as suggests the results of GMM model. Also in this case, there are asymmetric effects between the two groups of countries, for both kinds of pollutant indicators. With respect to PM10, foreign direct investment contributes to a reduction of air particulate pollution only in developed countries.

One by-product of this paper is the finding that international trade is helpful only in reducing CO2 emissions, with asymmetric effects between developed and developing countries, like we can see from Tables 5 and 6.

The increase of the per capita income is helpful in diminishing particulate air matter that represents a negative externality for current generations. This means that growth contributes to correcting the negative externality regarding the current generation, while in the case of externalities regarding future generations some economic policy will be needed to direct the world economies towards a more sustainable path. While the Kyoto protocol proves to have played a marginal role in explaining the level of air pollution emission, the price of fossil fuel may be of help to understand the CO2 and PM10 levels. The increasing scarcity of fossil fuel pushes technological development in search of a more efficient use of energy that, indirectly, reduces the emissions of carbon dioxide and particulate air matter in the atmosphere.

The results of regressions seem to confirm that there is an indirect effect of the TRIPs agreement in promoting domestic innovation and technology transfer via foreign direct investment. Moreover, it is worth noting that the effects of the TRIPs agreement strongly depend on the level of development of the countries considered in our sample.

Further and deeper analysis should be conducted in future to shed more light on this interesting issue.

Acknowledgements

I am grateful to the Associate Editor, prof. Jonas Šaparauskas, four anonymous referees, Dirk Czarnitzki, and participants to the 10th Annual International Industrial Organization Conference, held in Arlington, March 16–18 2012, to the seminar held at Durham University, Department of Economics, April, 25, 2012, at to 29th annual conference of European Association of Law and Economics held in Stockholm 20–22 September 2012, annual conference of Canadian of Law and Economics Association held in Toronto 27–28 September 2012, for invaluable suggestions regarding a previous draft of this work. All errors are the author's alone.

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