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Clean and Dirty International Technology Diffusion

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CLEAN AND DIRTY INTERNATIONAL TECHNOLOGY DIFFUSION*

Valentina Bosetti and Elena Verdolini +

Abstract

This paper investigates the role of Intellectual Property Rights (IPR) protection and Environmental Policies (EPs) on clean (renewable) and dirty (fossil-based) technology diffusion from top-innovators. IPR protection and EPs are extensively debated policy tools, as IPR protection addresses knowledge market failure, while EPs respond to pressing local and global environmental externalities. A model of monopolistic competition inspired by the recent trade literature shows that the profits associated with exporting a blueprint are a function of the quality of the idea and of market and institutional characteristics of the receiving country. We test the empirical implications of our model using patent data in renewable and fossil efficient power technologies for 13 top innovating countries and 40 patenting authorities. We improve on previous contributions by accounting for unobserved heterogeneity and for the endogeneity of policy proxies through a Generalized Method of Moment estimator. We show that knowledge transfer through patent duplication increases with the level of IPR protection, but with slight diminishing marginal returns. The effect is stronger for clean technologies, which are arguably less mature and more sensitive to uncertainty. Commitment to EPs also increases the incentives for patent duplication. The magnitude of the effect is conditional on the nature of the technology and on the specific policy instrument.

Keywords: Technology Diffusion and Transfer, Innovation, Patents, Energy Technologies, Environmental Policy, Intellectual Property Rights

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1 Introduction

The literature on the determinants of aggregate technical progress, which has tremendous repercussions on economic growth, focuses on understanding how innovation endogenously responds to economic forces (Romer [1990], Grossman and Helpmann [1991]). A crucial aspect in this respect is the bias of technological change towards particular factors of production, as argued in Acemoglu (2002). Issues of directed technical change are essential when studying policy mechanisms aiming at sustainable growth. The bias of innovation towards new and cleaner technologies or towards incumbent and dirtier production significantly affects not only the costs of reducing harmful anthropogenic pollution, but also the effectiveness of government policy intervention (Acemoglu et al. [2012]).

This paper contributes to the literature by testing how intellectual property rights protection and environmental policies, which are used primarily to influence the responses of the domestic research sector, impact the transfer of technology by top foreign inventors to the domestic market. Most of the analyses on the inducement effects of public policies focus on the endogenous domestic responses. However, the international diffusion and transfer of already available superior technologies through predictable and long-term signals and incentives is an equally important issue (de Conick et al. [2008], OECD [2011]).[1] Supporting such transfer of technologies would reduce duplication of research effort and would be particularly beneficial for those countries which are off the technological frontier, which would otherwise be unlikely to catch up given the weakness of their innovation sector (Evenson and Westphal [1995]).

The positive contribution of technology diffusion and transfer to economic growth through trade, Foreign Direct Investment (FDI) or labor mobility has been confirmed by a rich literature.[2] On the contrary, the extent to which domestic policies shape the diffusion and transfer of clean and dirty technologies from abroad has received little attention. These issues are of great relevance because

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[1] In this paper, the terms “technology diffusion” and “technology transfer” are used interchangeably and refer to the marketing of a new technology for production in a given market. This can be thought of as machines to produce a final good.

[2] See for example Coe and Helpman (1995), Bayoumi, Coe and Helpman (1999) on trade-related spillovers, Grossman (2013) on the role of labor mobility, Branstetter, Fishman and Foley (2006) on the role played by FDI.

countries that are still lagging behind in the development of clean innovation contribute substantially to multiple global environmental externalities. Hence, promoting the flow of less polluting technologies to those countries would lower the costs of compliance with stringent climate change targets for all countries, without impairing local sustainability and the domestic economy.[3]

Our analysis is novel in many respects. First, we draw on the recent literature on trade and technological transfers (Park [1999]; Helpmann, Melitz and Ribinstein [2008]; Eaton and Kortum [2009]) and environmental technical change (Acemoglu et al. [2012]) to sketch a general two sectors ("clean" and "dirty") model of transfer. The model identifies sending and receiving country characteristics which affect the diffusion of technological know-how.

Second, we show that cross-country patent applications are good candidates to study international technology transfer. Indeed, patents fit well the characteristics of our model, in which heterogeneous innovators are endowed with blueprints of different quality. Moreover, patents can be clustered into "clean" and "dirty" technological categories more easily than other indicators. Finally, patent applications in specific energy technologies are highly correlated with other (less available) proxies of market penetration and technology diffusion for clean and dirty technologies.

Third, we use patent data in clean and dirty technologies for the production of electricity to empirically test the model's predictions in a sample of 13 top innovating OECD countries and 40 receiving countries. Our focus on the power sector is dictated by its relevance with respect to energy security, sustainable growth and climate change (IEA [2012a]). While innovation in efficient and renewable technologies for power production is concentrated in few developed countries, securing clean and accessible electricity is a necessary step for countries off the technological frontier to support green and sustainable growth.

Fourth, core of the analysis is assessing to what extent two widely debated policy measures (namely, IPR protection and environmental policies) influence the transfer of superior technologies from

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[3] The rapid diffusion of more efficient and cleaner technologies to developing countries and emerging economies has such a critical role in international policies that a permanent international body (Subsidiary Body for Scientific and Technological Advice) has been created within the United Nations.

frontier innovators. Empirical evidence in this respect is rather scarce. IPR protection addresses the knowledge market failure by providing temporary monopoly rights to innovators, while environmental policy internalizes the costs of pollution. Their inducement role on innovation and technical change has been largely debated both in academic circles and in the policy realm, but to our knowledge no other contribution focuses on their contribution to clean and dirty technology transfer. The key question we address here is whether the effect of these two policy instruments differs between mature dirty technologies and less mature clean technological options.

Finally, a main matter of concern in our empirical application is dealing with the count data nature of our dependent variable while controlling for the endogeneity of the policy proxies. We address these issues by implementing an instrumental variable approach within a Generalized Method of Moments estimation framework in line with Blundell, Griffith and Windmeijer (2002), which uses pre-sample information to account for unobserved heterogeneity. This departs from most available literature on innovation and diffusion in clean energy production, in which these issues are often overlooked.

We show that IPR and environmental policies positively affect the rate at which both green and fossil efficient technologies for power production are transferred from innovating to receiving countries, but with diminishing marginal returns. A 1% increase in the strength of patent protection increases the probability of transfer of renewable ideas by 7.5%, while the corresponding effect on the probability of transferring efficient fossil fuel technologies is around 5%. Both general commitment to environmental policy and the number of policy instruments implemented in a given country have a positive effect on the transfer of foreign renewable and fossil blueprints. Specifically, market-based mechanisms are the ones to which foreign innovators in renewables respond more. Conversely, the innovators of efficient fossil technologies are attracted towards those markets which implement more technology policies to support cleaner production (as for example R&D tax breaks and other forms of public support to targeted R&D investments). The use of command-and-control instruments has on the contrary no discernible effect on the flow of foreign technologies.

The rest of the paper is organized as follows: Section 2 justifies the choice of patents as a proxy for technology diffusion and transfer, and sketches a model where the number of blueprints patented in a foreign country is a function of fixed and variable export costs, of the innovative activity of the sending country and the size of the receiving market. Section 3 describes trends of technology transfer through the patent system for the power sector, which is the focus of our empirical application and presents the estimation strategy. Sections 4 and 5 present the empirical results under the assumptions of exogeneity and endogeneity of the regressors, respectively. Section 6 concludes.

2 Technology diffusion and transfer through patents

Most previous literature focuses on trade, FDI or labor force mobility as important channels through which technologies and know-how diffuse internationally (Coe and Helpman [1995]; Eaton and Kortum [2002]; Hunt and Gauthier-Loiselle [2010]; Keller [2010]; Kerr and Lincoln [2010]). A few contributions use instead data on patent filings across countries to study the diffusion and transfer of technologies (Eaton and Kortum [1996], Branstetter, Fishman and Foley [2006], Eaton and Kortum [2009]).

Patents are legal titles providing a temporary monopoly power in a given market to the applicant.[4] The costs associated with a patent application are high, both in terms of information disclosure (knowledge spillovers) and in terms of patent filing fees, translation fees and agent's fees.[5] Hence, a patent application testifies that a (generally private) innovator is willing to pay to protect her idea. One

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[4] To be eligible for a patent, an invention (device, process, etc.) needs to be new, susceptible of industrial application and to involve a non-obvious inventive step. To obtain a patent, an inventor files an application to a patenting authority. The patenting office will check whether the application fulfils the relevant legal criteria and will grant or reject the patent accordingly. The limitations of patent data as an indicator of innovative activity are summarized in Griliches (1990), while their use as indicators of innovative activity is validated in a number of studies (Griliches, Pakes, and Hall [1987]; Pavitt and Soete [1980]; Sokoloff and Khan [1990]). In this extensive, literature patent data is used to study the dynamics of both innovation and inter-sectoral and international knowledge flow and spillovers at the firm, sector and country level (Jaffe [1986]; Jaffe and Trajtenberg [1996]; Jaffe, Trajtenberg and Henderson [1993]; Peri [2005]; Sakakibara and Branstetter [2001]). Applications to energy-related innovation include Lanjouw and Mody (1996), Jaffe and Palmer (1997), Popp (2002) and Verdolini and Galeotti (2011).

[5] Patent costs are heterogeneous across countries and depend on several components, among which official filing fees, agent's fee and translation fees. In the 1990s estimate ranges in Helfgott's (1993) go from USD 460 in India to USD 4,600 at the EPO, with the majority of countries lying in the range of USD 2,000 to 3,000. Lerner (2000) estimates the full cost of patent protection (including renewal fees) in 60 major countries. Only a handful, such as the Philippines, Paksitan, Kuwait and Egypt lie in the lower range (less than 100 1998USD), while the majority of countries has fees ranging from slightly less than 1,000 (Malaysia) to slightly above 15,000 (Japan). A Roland Berger Market research commissioned by the EPO in 2004 puts the costs of a Euro-direct and a Euro-PCT patent at 37,500 and 57,000 Euros, respectively, including all in-house costs for the firm (Roland Berger [2005]).

can therefore assume that the profits associated with the exploitation of the technology in the specific market more than compensate the patent applicant for the costs of patenting.[6]

Many case studies point to the role of patents as a means to protect a technology in foreign countries where the innovation will be marketed and sold. For example, Helfgott (1986), who served as the Head of General Electric's Foreign Patenting Operations, argues that firms patenting abroad strive to protect their innovations in markets where demand will be high. Boldrin and Levine (2013), point out that Foreign Direct Investment flows are directed towards those foreign sectors where patents are frequently used.

As a proxy of technology diffusion, patent data are used here to study how the decision of foreign innovators regarding the transfer of a blueprint is affected by domestic policy. The details which characterize patents allow focusing on both clean and dirty technologies, so as to explore the differential impact of domestic policies on these very different production options. In recent years, great effort has been devoted to identifying patent classes which help classify patents as clean or dirty.[7] In this lies the considerable advantage of patent data, one that other proxies used in the literature to study technology diffusion, such as trade and FDI, do not share. Focusing on patenting dynamics in the clean and dirty sectors, we thus provide important insights that complement the available studies focusing on other channels of transfer.

However, patent indicators are imperfect and suffer from a number of shortcomings which have been widely discussed in the literature (Griliches [1990]). Most relevant for our analysis is the fact that the number of technologies diffused from country *i* to country *j* through the patent system in each period of time (denoted T_{ij}) equals the number of patent applications from inventors in country *i* to country *j*'s patenting authorities (denoted PAT_{ij}) only under two very strict and unreasonable assumptions (Griliches [1990]). The first assumption is that all patents protect innovations of equal size and quality, while the

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[6] While licensing data would be extremely useful to access which patents are eventually worked in a given market, such data is extremely hard to come by in a cross country panel setting.

[7] In recent years great effort has been put towards tagging patent applications to identify green, renewable and more efficient innovation (see for example OECD [2012] and WIPO [2012])

second assumption is that all patent applications eventually result in a patent granted and licensed. However, patent applications do not inform on the quality of the innovation, the breadth of each patent, the length of the patenting process, nor do they provide information on whether the technology subsequently passes the test of patentability or is actually licensed.

We address these issues in two ways. First, in the data description section we substantiate our claim that patent flows mirror trade flows in specific technologies (Section 3). We also show that those countries towards which patent flows of specific technologies are higher are also the countries where these technologies are mostly used. While we cannot distinguish those patents which are licensed or those products which are imported or sold, the evidence we provide suggests that patent applications are indeed good indicators of technology diffusion and transfer.

Second, in our model we allow the relationship between the number of patent applications in a given market and the number of technologies diffused to that market to be strict but not perfect. Specifically, we define the relationship between transfer (T_{ij}) and applications (PAT_{ij}) as $T_{ij} = PAT_{ij}/\xi_{ij}$, where ξ_{ij} is a sending-receiving couple-specific effect that allows the average number of transferred technologies to differ across country couples. ξ_{ij} thus controls for (1) differences in the average size and quality of patents across innovating countries, such as the (unobservable) average number of claims and (2) differences in the probability that a patent application in country j is eventually granted protection and licensed.

To study the diffusion and transfer of technologies across countries, we develop a simple two-sector model inspired by recent contributions in the trade and innovation literature (Helpman, Melitz and Rubinstein [2008], Eaton and Kortum [2009]) and which fits well the characteristics of our empirical proxies, namely cross-country patent applications. The model identifies those factors influencing the decision of (heterogeneous) firms to transfer a blueprint to a foreign market. In this framework, the decision to export an idea - a recipe for production - depends on whether its implied productivity is above a threshold specific to the sending-receiving country pair.

Unlike the contributions focusing on bilateral trade, our focus is on the number of technologies crossing borders, not on the volume of trade, since patents only inform on the number of blueprints/technologies that firms willingly protect in a foreign country. Moreover, unlike Eaton and Kortum (2009), we distinguish between “clean” (renewable) and “dirty” (fossil-based) technologies to explore the differential impact (if any) of domestic policies on blueprints which improve the efficiency of the dirty incumbent technology versus blueprints developing new carbon-free technologies.

Consider a world with *j* economies indexed *j=1, 2, …, i, …, J* in which a research sector produces ideas and a productive sector produces a unique final good.[8] Every year innovators in the research sector of country *i* produce clean and dirty technologies according to the following knowledge production function:

$$R_{ist} = \omega_i KO_{ist}^{\alpha} \quad , \qquad s = clean,\ dirty \tag{1}$$

New knowledge is a function of own knowledge (KO_{ist}) available in each country to “stand on the shoulders of the giants” (Caballero and Jaffe [1993], Eaton and Kortum [2009]) and the average productivity of research in country i (ω_i). Technologies invented in *i* are heterogeneous and differ along $a \in \mathbb{A}$, the recipe quality dimension. A higher a means that a specific output can be produced with smaller amounts of factors of production.[9] Each idea is protected through the patent system, as a result of which the innovator effectively gains a temporary monopoly power on the innovation.[10] Each innovator chooses in how many markets to seek protection on the basis of the quality of her idea. The world's market for technology is thus characterized by monopolistic competition.

In each economy j, a unique final good is produced competitively using “clean” and “dirty” inputs, Y_{jc} and Y_{jd}, according to the following aggregate production function:

$$Y_j = \left[Y_{jc}^{\frac{\varepsilon-1}{\varepsilon}} + Y_{jd}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

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[8] In what follows, *i* is the country where ideas originate and *j* is the country where the ideas are transferred.

[9] Inputs and factor inputs are measured in units of constant quality.

[10] Patent protection effectively grants the innovator the ability to exploit the property rights on the innovation which generally amounts to 30 years.

Where $\varepsilon \in (0, +\infty)$ is the elasticity of substitution between the two inputs. Each of the two inputs, Y_{js}, is produced using a continuum of sector-specific technologies[11] such that:

$$Y_{js} = \left[\int_0^{A_{js}} y_{js}^{\frac{\sigma_s - 1}{\sigma_s}}\, ds\right]^{\frac{\sigma_s}{\sigma_s - 1}} \tag{3}$$

where the parameter $\sigma_s \in (0, +\infty)$ represents the elasticity of substitution across varieties A_{js} available in country j and might differ across the "dirty" and "clean" sectors. Technical progress, which is the result of both innovation and technological transfer, takes the form of increases in A_{js} or number of blueprints available in country j. Technology transfer is modeled by allowing the recipes of each country to originate in any of the n research sectors of the world. Hence, blueprints can originate in country j or can be imported in country j from innovators in any other foreign country, i. As the quality of ideas a is heterogeneous, ideas of high quality a_H are patented widely (in more than one country), while ideas of low quality a_L might be patented in only one country or not at all. We model a as the realization of a random variable drawn from a Pareto distribution with a shape parameter $\theta > 1$, so that the fraction of ideas with quality higher than a is $a^{-\theta}$ (Helpman, Melitz and Rubinstein [2008]).[12]

Given the structure for the production of the final output, the optimal levels of Y_{jc} and Y_{jd}, given total spending, M_j, in country j are:

$$Y_{js} = M_j \left(\frac{P_{js}}{P_j}\right)^{-\varepsilon} \tag{4}$$

Where P_j is the country price index, $P_j = \left({P_{jd}}^{1-\varepsilon} + {P_{jc}}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$, P_{js} is the price index for each of the two sub-nests $P_{js} = \left[\int_0^{A_{js}} p_{js}^{1-\sigma_s} ds\right]^{\frac{1}{1-\sigma_s}}$ and p_{js} is the price of each variety y_{js} . Finally, total demand in country j for any variety y_{js} is:

$$y_{js} = M_j \left(\frac{p_{js}}{P_{js}}\right)^{-\sigma_s} \left(\frac{P_{js}}{P_j}\right)^{-\varepsilon} \tag{5}$$

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[11] Production in both sectors will depend also on the use of labor and natural resources, but, as the focus of the paper is on technologies, we will keep our attention on the capital portion of production and abstract from the contribution of labor and natural resources, as they appear as part of the bundle to which variable costs refer.

[12] We are implying that the location parameter is 1.

The value of a patent in any country j, will depend on the profit which that specific recipe is able to generate in country j. As we have seen, the idea could be generated in any country *i*, with *i* equal or different from *j*.

The cost of producing one unit of output in country j with a recipe originating in country i is $\tau_{ij}C_{js}/a$, where C_{js} can be thought of as the country-specific cost of a bundle of individual factor inputs, combined according to the recipe a.[13] C_{js} may also differ between the dirty and clean power technologies to reflect differences in the level of internalization of the social cost of the dirty input or subsidies to renewables.

The τ_{ij} factor, which is similar to the melting iceberg specification of exporting costs, reflects here the additional unit costs borne by producers in *j* which use a recipe originating in *i*. τ_{ij} is specified as a function of bilateral country characteristics (D_{ij}) capturing distance-related barriers to transfer: ${\tau_{ij}}^{\theta} = D_{ij}^{\gamma}e^{-u_{ij}}$ where u_{ij} are i.i.d. unmeasured country-pair specific frictions. Furthermore, we normalize $\tau_{ii} = 1$ and assume that $\tau_{ij} > 1$. These assumptions are consistent with the fact that exporting an idea to another country is more costly than serving the home market (Helpman, Melitz and Rubinstein [2008]). If the inventor country produces and markets the given good in market *j*, distance will matter as goods need to be physically transferred. However, distance is likely to also play a role if a foreign inventor decides to license to a local producer or to a subsidiary. In this case, some tacit knowledge is embedded in the innovation and needs to be transferred to the foreign market. The greater the geographical, linguistic and cultural distance between the countries, the more complicated and expensive the transfer is. In addition, we include a country-specific fixed costs term F_j to capture all lump-sum costs.

The price charged for an intermediate good produced with an idea of quality a originated in *i*, when selling it in country *j* is therefore:

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[13] There are two possible cases. First, the i-innovator can licence the patent to i-firms, which will export the good to the j-market. Second, the i-innovator can licence the patent to j-firms, which will produce the good locally. In any case, the monopolistic nature of the knowledge market means that the innovator is the one who reaps all the economic benefits associated with the innovation. In what follows, we assume that production is relocated to the j market, hence the cost of producing is indexed by j.

$$p_{ijs} = \frac{\tau_{ij} C_{js}}{\beta_s a} \tag{6}$$

where $\frac{1}{\beta_s} = \frac{\sigma_s}{\sigma_s - 1}$ is the standard Dixit-Stiglitz (1977) mark-up.

As a result, the associated operating profits in country *j* of adopting a technology whose recipe originated in country *i* are:

$$\pi_{ijs}(a) = [1 - \beta_s] \left(\frac{\tau_{ij} C_{js}}{\beta_s a}\right)^{1-\sigma_s} M_j P_{js}^{\sigma_s - \varepsilon} P_j^{\varepsilon} - F_j \tag{7}$$

The owner of an idea in country *i* will seek a patent in any country *j* if the profit associated with the quality of her idea *a* is greater than 0, or, alternatively, if

$$[1 - \beta_s] \left(\frac{\tau_{ij} C_{js}}{\beta_s a}\right)^{1-\sigma_s} M_j P_{js}^{\sigma_s - \varepsilon} P_j^{\varepsilon} > F_j \tag{8}$$

This equation then implicitly defines the cut off value $\bar{a}_{ijs}$: country-*i* blueprints of value $a > \bar{a}_{ijs}$ will be protected by patent in country *j*. The threshold quality $\bar{a}_{ijs}$ varies across different destination countries, so that an idea may be patented in some countries but not in others; it may also be different for the two clean and dirty technologies. These assumptions are consistent with previous literature (Scott-Morton [1999]).

Given our assumptions on the distribution of *a* and on the threshold $\bar{a}_{ijs}$, it follows that the number of ideas originating from country *i* and patented in country *j* is $T_{ijs}(a) = \bar{a}_{ijs}^{-\theta} R_{is}$, where R_{is} is the stock of ideas which originated in *i*. If $a < \bar{a}_{ijs}$: for all country-*i* firms, no idea originating in country *i* will be patented in country *j*. If $a > \bar{a}_{ijs}$ for at least one firm in country *i*:

$$T_{ijs} = \left[F_j\right]^{-\frac{\theta}{\sigma_s - 1}} (1 - \beta)^{\frac{\theta}{\sigma_s - 1}} \left[M_j\right]^{\frac{\theta}{\sigma_s - 1}} \left[{P_{js}}^{\sigma_s - \varepsilon} {P_j}^{\varepsilon}\right]^{\frac{\theta}{\sigma_s - 1}} \left(\frac{\tau_{ij} C_{js}}{\beta_s}\right)^{-\theta} \left[R_{is}\right] \tag{9}$$

Substituting into (9) the expressions for τ_{ij} and R_{is} and accounting for the relationship between technology transfer (T_{ijs}) and patent applications (PAT_{ijs}), bilateral transfer becomes:

$$PAT_{ijs} = KO_{ist}^{\alpha} \left[D_{ij}\right]^{-\gamma} [F_j^{\frac{1}{\sigma_s - 1}} C_{js}]^{-\theta} [M_j]^{\frac{\theta}{\sigma_s - 1}} \left[{P_{js}}^{\sigma_s - \varepsilon} {P_j}^{\varepsilon}\right]^{\frac{\theta}{\sigma_s - 1}} \left[\beta (1 - \beta)^{\frac{1}{\sigma_s - 1}}\right]^{\theta} \bar{\xi}_{ij} e^{u_{ij}} \tag{10}$$

where $\bar{\xi}_{ij} = \omega_i \xi_{ij}$. The number of patent applications from inventors in country *i* and to country *j*’s patenting authority is (1) increasing in the sending country's knowledge stock $\left(KO_{ist}\right)$, (2) decreasing in bilateral distance between the sending country i and the receiving country j $\left(D_{ij}\right)$, (3) decreasing in the costs of production in j $\left(F_j^{\frac{1}{\sigma_s-1}} C_{js}\right)$ and, for values of σ_s greater than 1, (4) increasing in the market size in country j $\left(M_j\right)$, (5) increasing in the price of the good in country j, $\left({P_{js}}^{\sigma_s-\varepsilon}{P_j}^{\varepsilon}\right)$.[14] Equation (10) also accounts for sending-receiving countries fixed effects $\left(\bar{\xi}_{\mathrm{ij}} = \omega_i \xi_{\mathrm{ij}}\right)$ and an error term $(e^{u_{ij}})$.

Focus of this paper is how policy levers, either targeting innovation or the environment, might affect the propensity to transfer clean and dirty technologies by altering their costs. On one hand, IPR protection affects the payoffs associated with a clean or dirty blueprint because it is inversely related to the likelihood of imitation. If property rights are better protected and enforced, the benefits associated with marketing a technology in a given country are less uncertain. Besides creating incentives for domestic innovators, stronger patent protection also impacts the transfer of innovation from abroad (Hall and Helmers [2010]). However, a rich literature highlights that the effect of stronger patent rights on the transfer of foreign technologies is not clear *a priori* (Maskus [2000, 2012]).

On one hand, if exclusivity is better protected, ownership rights are better defined and inventors and patent holders face higher financial returns from exploiting their innovation, as uncertainty and the likelihood of imitation are lower. In this sense, stronger IPR protection could have a positive effect on foreign technology transfer. Eaton and Kortum (1996), for example, assume that transfer is negatively correlated with a lax IPR system: the higher is the likelihood that an idea will be imitated, the less likely is the transfer. This effect might be particularly important for those (laggard) countries which could benefit by becoming attractive markets for transfer through better protection of (domestic and foreign) patent rights.

On the other hand, the choice of the strength of IPR protection in any country is influenced by the level of development, the innovative ability, the knowledge stock of home innovators as well as the

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[14] In our empirical application, which focuses on the power sector, we assume this to be the case. Econometric studies of inter-fuel substitution in fossil fuel powered generation report values of the elasticity of substitution in the range of 1 to 3, for example in Ko and Dahl (2001) and Soderhölm (1998).

characteristics of the innovation sector. Countries which lag behind the innovation frontier may support lax property rights in an effort to gain from imitating the innovations of more advanced countries. As these countries develop and strengthen their domestic innovation capacity, stronger IPR protection is advocated (see for example Ginarte and Park [1997]). If more stringent IPRs arise from the demands of a growing domestic research sector, IPR reforms can give rise to powerful market power effects.

Moreover, if the market effects are reaped by domestic firms, foreign technologies might be crowded out. In this case, stronger IPR protection might result in slower technology diffusion from abroad. The effect of stronger IPR measures on transfer might not be linear. Quian (2007), for instance, argues that in the case of pharmaceuticals, increasing the stringency of the patent system was beneficial but with decreasing marginal returns.

The effect of stronger property rights policies might also be conditional on specific market characteristics of the technologies under consideration. When substitutability between technologies is high, stronger IPR protection will less likely represent a barrier to entry for new firms or higher prices for consumers (Barton and Osborne [2007]). The picture is therefore arguably different for sectors with different characteristics, for example pharmaceuticals as compared with power production. We contribute to the literature by focusing on how changes in IPR regimes affect the transfer of high quality clean and dirty blueprints from abroad in the power sector.[15]

The second major factor likely to affect the relative cost of clean and dirty technologies, hence affecting the likelihood of their transfer, is the presence of environmental policies. Environmental policies promote cleaner ways of production. This can come about in two ways. On the one hand, they can promote the efficiency of technologies using the dirty input, thus resulting in fewer emissions per unit of output. On the other hand, producers can drop the incumbent dirty technology and turn to renewable and clean production methods, for which the pollution byproduct is in fact close to zero, net of life-cycle assessments.

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[15] See Eaton and Kortum (1996) for the effect of IPR on general innovation, Hall and Ziedonis (2001) for semiconductors and Qian (2007) for pharmaceuticals.

To this end, policy makers can either directly regulate pollution or they can support innovation of cleaner technologies. With respect to directly regulating pollution, economists distinguish between two approaches depending on the level of flexibility a given policy provides to firms or consumers. Command-and-Control (C&C) policies such as Standards, or Mandates set a target in terms of emission reduction or clean production, and thus provide little additional incentives to go above and beyond the required pollution reductions. C&C policies increase the fixed and variable costs because of the shadow price of the imposed constraints. If C&C policies result in absolute bans, they effectively raise the costs of producing with dirty inputs up to infinity. Conversely, Market Based policies (MB) such as pollution taxes, subsidies, as feed-in tariffs, or other economic incentives induce cost-effective pollution control by changing the relative prices of the clean versus dirty technologies.

These two sets of instruments are characterized by different effectiveness and long and short run incentives (Hahn and Stavins [1992], Goulder and Parry [2008]). The comparison of C&C versus MB instruments, which is often based on highly stylized theoretical analyses under assumptions of perfect information, zero transaction costs and perfect enforceability and with little attention to political constraints, concludes that the dynamic incentives of MB policies for domestic innovators are higher (Hahn and Stavins [1992]). Being focused on the actual diffusion of cleaner technologies, this result should carry over in a straightforward manner to foreign innovators. By providing flexibility to the innovators, MB policies likely provide greater incentives also for the transfer of foreign technologies.

Finally, environmental policies following the “technology” channel, either in the form of public direct investment, RD&D programs or tax breaks, are meant to overcome the knowledge externality of environmental – friendly technologies rather than directly targeting reductions in harmful pollutants. Technology-specific environmental policies thus work in the direction of lowering the cost of innovation of a given technology and are traditionally targeted at the home research sector. Hence they are likely to have little direct impact on the choice of foreign firms to transfer an already existing blueprint. In this sense, they could lead to a strengthening of the local research sector and crowd out foreign technology transfer. However, they might also have a positive indirect effect as they contribute to the creation of a market for clean and efficient technologies. The overall effect will depend on the nature of the technology under consideration, on specific market characteristics and on the domestic research sector.

In this paper, we empirically test the effectiveness of these three different families of environmental policies on the inward transfer of foreign top innovator technology. As explained more in detail in the next section, we develop two empirical proxies to this end. First, an index captures the commitment of a given country to environmental protection and to supporting clean production technologies. Second, an indicator measuring the diversity of the policy instrument portfolio gauges if the combination of different policy approaches is beneficial for transfer. Finally, we focus on the three different kinds of instruments presented above and study the relative impact of C&C, MB and technology policies on the diffusion of foreign technology.

To test the prediction of our model and to explore what role IPR and environmental policy have on international technology transfer, we focus our empirical application on clean and dirty power production. The next section presents a descriptive analysis of international technology transfer in this sector and a detailed description of the variables used in empirical estimation and estimation strategy. Empirical results follow.

3 Data and Empirical Estimation

The power sector is a perfect case study to test the empirical predictions emerging from our model and to assess the role of IPR and environmental policy on technology transfer. This sector is at the center of the political debate regarding sustainable growth. Power is a General Purpose Technology, namely an “enabling technology” the diffusion of which has long-lasting impacts on the organization of production and long term economic growth (David [1990]; Bresnahan and Trajtenberg [1995]; Moser and Nicholas [2004]; Helpman [1998]). The negative externality associated with the production of electricity from fossil inputs has been addressed in many countries through environmental policies supporting cleaner (more energy efficient or renewable) production technologies. Issues of directed technical change in this sector are particularly relevant in light of the high capital investment characterizing power production. The widespread diffusion of clean or dirty power technologies thus has important repercussions on the entire economy. This aspect is particularly crucial for developing countries, where energy poverty still affects a large share of the population.

We extract data on patent applications for power production technologies from the EP-KITeS Patent Statistics Database (KITeS [2010], Lissoni, Tarasconi and Sanditov [2006]), which includes patents from over 90 patent offices worldwide, including regional offices and WIPO.[16] We attribute each patent application to either the clean or the dirty sector using the list of patent codes listed in the Supplementary Table I. Efficient fossil-fuel power technologies include those technologies which significantly increase the efficiency of power production through fuel preparation (e.g. Coal gasification, Coal pulverization, Coal drying), improvements in turbines and boilers (e.g. Improved Boilers for Steam Generation, Improved Steam Engines, Super-Heaters, Improved Gas Turbines and Improved Compressed Ignition Engines) or combined cycles for co-generation of electricity and heat. Renewable technologies include Hydro, Solar, Wind, Ocean, Biomass and Geothermal.[17]

Our sample includes 25,653 and 28,200 new blueprints in renewable and efficient fossil power technologies originating from 13 top innovating OECD countries between 1990 and 2007.[18] We track the pattern of application to 40 foreign patenting authorities, including both OECD and non-OECD countries. Table I includes the list of innovating countries and provides some descriptive statistics.

As in the case of general innovation, few developed countries account for most of the innovation in, and the technological improvement of, renewable and fossil efficient electricity production technologies. Also, the high number of duplicate applications suggests that technical change in countries

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[16] The database includes the full set of bibliographic variables concerning each patent application, such as priority, application and publication numbers and dates, information on inventors and applicants, legal status, and references (citations) to prior-art patents and to non-patent literature.

[17] Our selection relied on an extensive literature which identified the IPC codes under which innovation in renewable and efficient fossil power production are classified. The IPC codes for efficient fossil technologies are a refinement of those presented in Lanzi, Verdolini and Haščič (2011), while renewable energy technologies codes were compiled from a number of sources that previously conducted searches in this respect, among which Lanjouw and Mody (1996) and Johnstone, Haščič and Popp (2010).

[18] A top innovating country is a country whose research sector over the sample period produced more than 1,000 new ideas (patent applications) in the technologies under consideration.

away from the innovation frontier is strongly influenced by the international diffusion of power production technologies (Haščič et al. [2010], Keller [2004], Lanzi, Verdolini and Haščič [2011]).

[Table I around here]

Patent duplication from top OECD economies in the period 1990-2007 was substantial for both fossil and renewable technologies, albeit with important differences between these two technologies. The 25,653 and 28,200 clean and fossil-based blueprints gave rise to more than 40,000 and 53,000 duplicate applications. Overall, fossil patents have a higher per patent duplication rate, arguably indicating that these technologies are incumbent with respect to electricity production. These technologies have a more widespread application due to the great availability of fossil inputs: coal reserves are widespread and available in the majority of countries; gas, which is the second input in share terms for electricity production, is extensively traded. Moreover, in the absence of a policy internalizing GHG emission and pollution, efficient fossil technologies have lower production costs than renewables in most countries.

Not surprisingly, top innovators in both fossil and renewable power technologies are the USA, Germany and Japan. These countries, however, do not lead in terms of intensity of patent duplication, in which other countries in our sample perform better. On average, Swiss renewable blueprints are applied for in 3.72 additional application authorities, while Dutch fossil-based efficient power generation technologies are applied for in 3.54 additional markets. Technology transfer is significant in our sample, with each "idea" giving rise, on average, to 1.6 and 1.9 additional patent applications for renewable energy and fossil, respectively.

One of the main assumptions on which our analysis relies is that patent duplications mirror technology diffusion flows and that patent application reflect the marketing of a given technology. Due to data limitations, we cannot check the validity of this assumption on the whole sample, but we can provide insights relative to some specific power production technologies. First, we identify the bilateral trade of goods which is specific to wind turbine technologies from UN COMTRADE (2012) (Wind [2008]). In this specific technological field, the correlation between the stock of foreign patent applications in

2007 and incoming trade flows over the period 2007 and 2011 is 0.75 and statistically significant. Second, the correlation between the stock of patents in wind and solar technologies present in the receiving country in 2009 and the installed capacities in the same technologies (IEA [2012b]) is 0.58 and statistically significant. This evidence supports our assumption that patent application abroad mirrors technology diffusion.

Based on equation (10) from our theoretical model we analyze renewable power technologies separately from fossil-fuel power technologies. While both renewable and efficient fossil technologies reduce the amount of harmful emissions linked with power production, the level of development of these technologies is starkly different. Fossil-fuel based electricity production has been the backbone of the world's energy systems, providing reliable energy at the cost of anthropogenic CO2 emissions. Efficiency improvements in this case can be implemented with great cost variations, but without production paradigm shifts. Conversely, renewable technologies (with the exception of hydropower) have entered the market only recently. Notwithstanding an average annual growth rate of 13% over the last 10 years, they currently supply only 3% of worldwide electricity production. Renewables are associated with drastic changes in the way electricity is produced and fed into the grid and have received widespread attention for their potential to ease the pressure on the environment and the dependence on fossil sources (IEA [2012a]). Focus of the debate is how to improve their intermittency, lower their high costs and cope with dependence on geographical factors.

Having introduced our dependent variable, we summarize in Table II the variables and data sources used in the empirical analysis. We start by describing those variables characterizing each couple of countries engaged in the transfer relation. To measure the distance between sending and receiving countries, we follow the rich trade and innovation literature and include three different indicators, each capturing a specific aspect of distance. First, geographical distance between *i* and *j* is measured in thousands of kilometers. Second, we include a dummy variable equal to one for the presence of a colonial relationship between *i* and *j*. This variable accounts for the possibility that technology transfer is more likely if countries are used to dealing with each other and have had long lasting ties. Finally, a dummy variable equals 1 if the two countries have a common language.

Previous studies show that the geographical vicinity, colonial ties and common language positively affect both trade and knowledge flows (Jaffe, Trajtenberg and Henderson [1993] and Jaffe and Trajtenberg [1996], Helpman, Melitz and Rubinstein [2008], among others). With respect to spillovers in energy technologies, Verdolini and Galeotti (2011) conclude that geographical distance does affect the magnitude of spillovers, but its impact is lower than in the case of general technologies analyzed in the literature.

Among the distance variables, we expect the role of language to be prominent: physical distance in the case of blueprint transfer might have a lesser role than in the case of trade. However, if countries have a different language, applying for a patent in the receiving country will be more costly because the patent needs to be translated (Helfgott [1993]).

[Table II around here]

We now turn to the characteristics of the sending country which affect the level of bilateral transfer. As described in equation (1), innovation in country *i* at time *t* in technology *s* (R_{its}) is a function of own technology-specific patent stocks, which proxies for a country's innovative ability. Following previous literature, we compute the own stock of knowledge in the innovating country *i* using the perpetual inventory method on the count of applications (singulars and claimed priorities) worldwide by innovators from country *i* in technology *s*:

$$KO_{ist} = Pat_{ist} + (1 - \delta)K_{ist-1} \tag{11}$$

where $\delta = 0.1$ is the depreciation rate (Keller [2002]).[19] The knowledge stock variable is normalized so that a one unit increase in the variable indicates an increase of 100 patents in the knowledge stock.

We now turn to the relevant characteristics of the receiving country. First, the number of

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[19] The results presented here are robust to choosing different discount rates, in the range of 0.5 to 0.15. The initial value of the stock KO_{ist_0} is defined as: $KO_{ist_0} = \frac{PAT_{ist_0}}{(\bar{g}_{is}+\delta)}$ where $\bar{g}_{is}$ is the average rate of growth of patenting in technological field s for the period between t_0 and $t_0 - 4$. We use $t_0 = 1975$ as the initial year to compute the knowledge stock, while the empirical analysis starts in 1990. This ensures that the choice of the initial value of the knowledge stock has a minimum impact on the variable itself.

blueprints transferred to any given market is positively correlated with expenditures for power. Love-of-variety models are based on the assumption that as the market gets bigger, it can support a wider range of production technologies (Grossman and Helpman [1989]). We control for the size of the market for electricity in *j* (M_j in the model) by including the lagged value of electric power consumption measured in TWh.

The absorptive capacity of the receiving country also plays an important role in the decision of profit-maximizing firms to market a given technology (Cohen and Levinthal [1990]). Unless the recipient is willing and able to exploit the superior technology, the costs associated with patent applications abroad will not be recouped by the innovator. We assume that absorptive capacity in power technology is specific for clean and dirty technologies, as the two categories of technologies have distinct features. We control for the technology-specific absorption capacity of country j by including in the estimation the number of patent applications in clean/dirty technologies the country produced in a given year.[20]

Finally, foreign patent applications are a decreasing function of fixed and variable costs, which are in turn affected by IPR and environmental policy. We measure the quality of the IPR system by the Ginarte and Park (GP hereafter) index of IPR (Ginarte and Park [1997], updated in Park, [2008]) which rates the strength of national IPR regimes of 122 countries on a scale from zero to five at intervals of 5 years.[21] We interpolate the missing values and transform the index on a 0 to 100 scale. We test the hypothesis of diminishing marginal returns to stronger IPR protection by including the squared value of the GP index in the empirical estimation.

The GP index has the major limitation of measuring only the strengths of the law of patent protection, not its actual implementation. For any given quality of the patent system, costs will be lower and transfer will be higher in those countries which successfully implement the law and respect it. For this

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[20] Renewables power technologies have an additional peculiarity in that their potential is constrained by the natural potential. This is, however, an almost fixed characteristic of each country and we assume it is fully captured by the country fixed effects.

[21] To compute the ranking, Park and Ginarte create five different categories, namely the extent of coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms, and duration of protection. They define several benchmark criteria, such as the patentability of pharmaceuticals for extent of coverage. Ginarte and Park (1997) compute the share of "fulfilled" criteria in each category for each country. A country's score is the unweighted sum of these shares over all categories. The index is calculated in 5-year intervals. See Ginarte and Park (1997) and Park (2008) for details.

reason, we include in the estimation an additional index, “Rule of Law”, provided by the ICRG (2011) The “Rule of Law” indicator ranges between 1 and 5 and is provided monthly. We average the data for each year and country and rescale it between 0 and 100. We expect this variable to have a positive impact on bilateral transfer: if law and order are respected, economic transaction are more secure, the rights of all parties are well defined and defended and there is less uncertainty on the economic and legal outcomes. Moreover, rule of law is by definition negatively correlated with corruption, which is often an additional cost of serving any given market. Incidentally, the inclusion of the “Law and Order” index serves also the purpose of controlling for the likelihood that environmental policy is respected (see below). Conditional on a given level of “Law and Order”, countries with a higher commitment to environmental policies will likely be the target of more transfer.

An additional matter of concern regarding the level of protection of IPRs is that it might be endogenous. Countries might choose a level of IPR protection which is dependent on their general innovative capability: a more stringent IPR might be the consequence of a rising domestic research sector demanding better and stronger protection for indigenous innovation (Ginarte and Park [1997]). Striking a balance between the potential of imitating foreign technologies and the need to encourage domestic innovation is likely to play a relevant role in developing countries (Chen and Puttitanun [2005]). Most of the empirical analyses on the role of IPR on innovation, knowledge transfer and diffusion do not address the endogeneity of the IPR regime and take IPR indicators as exogenous. Among the few exceptions, Chen and Puttitanun (2005) focus on developing countries and show that the level of IPR protection is raising the countries’ innovative ability. We address the issue of endogeneity of the IPR regime through an instrumental variable approach, which we describe and discuss in detail in the next Section.

Finally, we control for the presence of environmental policy in the receiving country. Building an indicator of EP is a rather complex task, as policies are heterogeneous in nature, strength and objectives. For the aim of this paper, we are interested in measuring both overall commitment to cleaner power production and diversity of the policy instrument portfolio. Committing to environmental protection is a signal to innovators and patent holders worldwide that demand for cleaner technologies will likely increase in the coming years in that specific market. Moreover, the decision to tackle environmental problems by resorting to various policy instruments (C&C versus MB or technology) is likely to influence the response of foreign innovators. The direction of this influence is however not clear a priori. On the one hand, many different policy interventions can increase uncertainty and complexity, reducing incentives for diffusion. On the other hand, this could be seen as a signal of strong commitment as more than one route is chosen to address the environmental externality.

We collect data on the environmental policies specifically targeting the power sector from the IEA World Energy Outlook policy database (IEA [2010]) and develop two distinct proxies. The first one is a policy "stock", namely the sum over time of the policies introduced in any given country. The second indicator focuses instead on the characteristics of the policy portfolio. We identify 10 different types of environmental policy that governments can choose to implement in order to address climate-related concerns in the electricity sectors ranging from C&C measures to MB instruments and including R&D subsidies.[22] We assign a value of 1 to the implementation of any policy in each policy type and sum these values for a given country in each year. The index thus varies between 0 and 10 and reflects the breadth of the instrument choice in any given country. To explore the differential impact of C&C, MB and Technology policy on the clean and dirty technology diffusion we use the same methodology of this last index to create a different variable for each of these categories.

These indices of environmental policy commitment suffer from two major problems. First, counting the number of environmental policies targeting the electricity sector is less than an optimal indicator, even though similar indices have been previously proposed in the literature (Dasgupta et al [2001], Nesta, Vona and Nicolli [2012] among others). The scope, design and enforcing will differ by country, so that this indicator is plagued with measurement error. This notwithstanding, governments do not commit to specific environmental measures lightly, and the passing of a set of laws regulating the power sector in favor of cleaner technologies is the outcome of very lengthy processes that involve the

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[22] We identify ten different policy instruments which have been implemented by countries in our sample over time to promote efficient and renewable power generation: Taxes, Feed-in Tariffs, Subsidies and Incentives, Permits, Standard, Mandates, Labelling, Quotas, R&D, and direct Investment in capital goods.

voting of parties, the support of public opinion, and the respect of international treaties and commitments, especially in a crucial sector such as energy supply. Hence we believe that, net of an intrinsic measurement error, our proxies should credibly measure in a qualitative way the magnitude of commitments of different countries.

Second, these policy indicators are endogenous: the choice of implementing a policy supporting more efficient and less polluting technology is influenced by availability of technological alternatives, the strength of the domestic research sector and the overall ability to enforce policy. Specifically, countries with high domestic innovation and greater IPR strength will more easily commit to environmental protection through public policy. If the supply of energy-related blueprints is high, compliance with environmental policy will be achieved at lower costs and public support for environmental policy will be higher (Barrett [1994], Carrion-Flores and Innes [2010]). Indeed, this has been documented to be the case for the Montreal Protocol, the agreement aiming at curbing CFCs gases that largely benefited from the development of new refrigerator technologies (Puller [2006]). Again, we resort to an instrumental variable approach to correct both the measurement error issues and the endogeneity of the environmental policy variable.

We turn now to the empirical estimation strategy. We model the transfer patent application from inventors in *i* to country *j* (pair *p*) in a given technology *s=c,d* at time *t* (a count variable) through an exponential model with an additive error of the form:

$$PAT_{ps,t} = exp\left(X_{ps,t-1}\beta_X + \beta_{st}\right) + \varepsilon_{st} \tag{12}$$

where $PAT_{ps,t}$ is the number of patent applications between each p country-pairs at time t, $X_{ps,t-1}$is a vector of explanatory variables at time t-1, β_{st} are the coefficients associated with time dummies and capture all common macro shocks and ε_{st} is an i.i.d. error component. If unobserved heterogeneity η_{ps} is not appropriately accounted for, estimates from Equation (13) are likely biased. We model the unobserved component η_s multiplicatively (Windmeijer and Santos-Silva [1997]):

$$PAT_{ps,t} = exp\left(X_{ps,t-1}\beta + \beta_{st} + \eta_{ps}\right) + \varepsilon_{st} \tag{13}$$

We assume that the ε_{st} are not serially correlated, $E\left[\varepsilon_{st}\eta_{ps}\right] = 0,\ t = 1, \dots, T$ and allow for correlation between the individual effects and the regressors, $E\left[X_{ps,t-1}\ \eta_{ps}\right] \neq 0$. Choosing an appropriate estimation approach for (14) we thus also need to control for the endogeneity bias of our policy regressors, which might respond to unobservables affecting the bilateral transfer of technology, as previously explained.

We address both unobserved heterogeneity and endogeneity issues by implementing the pre-sample mean estimator proposed by Blundell, Griffith and Windmeijer (2002) for count data dependent variables. In this framework, the log of pre-sample mean bilateral transfer is used to control for pair-specific unobserved heterogeneity. This estimator is thus well suited for patent data, which have long historical series. The exponential model is estimated through a Generalized Method of Moments (GMM) approach which allows us to also relax the assumption on the exogeneity of the policy variables. For each *s=c,d* technology, the Moment Conditions are as follows:

$$\frac{1}{P}\sum_{p=1}^{P}\sum_{t=1}^{T} Z_{pst-1}\left(y_{pst} - \exp(\beta_{0s} + X_{pst-1}\beta - \phi\ln\bar{y}_{ps0})\right) = 0 \qquad (14)$$

Where P indicates the number of country pairs, T indicates the years (1990-2007), $ln\,\bar{y}_{ps0}$ is the pair pre-sample mean calculated between 1970 and 1989, X_{pst} is the vector of regressors as previously explained. Z_{pst} is equal to X_{pst} when we assume that the regressors are exogenous. Conversely, when accounting for the endogeneity of our policy variables, $Z_{pt} = \left(1, EX_{ps,t-1}, IV_{ps,t-k}\right)$. $EX_{ps,t-1}$ includes the set of original regressors which are treated as exogenous, while $IV_{ps,t-k}$ are a set of instruments which we discuss in Section 5.

4 Baseline Empirical Results

Table III presents the results of the empirical estimation for renewable (R) and efficient fossil (F) patent transfer. The first benchmark specification for each of the two technologies (colums R1 and F1) is a pooled Poisson estimation with country dummies. The second and the third columns (R2, R3 and F2, F3) present the results of the GMM pre-sample mean estimator under the assumption of regressors exogeneity and endogeneity, respectively. The main purpose of the comparison of the pooled Poisson estimation and the GMM pre-sample mean estimations is to highlight biases in the estimation of the coefficients when overlooking the issues of unobserved heterogeneity on the one hand and that of policy endogeneity, on the other. Such a comparison seems particularly useful for an energy-related application like ours because pooled count data models with country dummies have often been used in available empirical analyses focusing on the energy sector.

[Table III around here]

We focus in this section on the specifications based on the assumption of regressors exogeneity (R2 for renewables and F2 for efficient fossil), while we address endogeneity issues in the next section. We start from those variables proxying for bilateral distance. The coefficients associated with the distance variables in both the renewable and fossil specifications are not statistically different from zero, with the exception of the language dummy in the renewable specification. The coefficient associated with common language has the expected sign. The difference in estimates with the basic pooled Poisson model suggests that disregarding the presence of unobserved heterogeneity leads to an overestimation of the contribution of distance to bilateral transfer. These biases are substantial: in both specifications the coefficient associated with distance drops by more than an order of magnitude and becomes insignificant. In the case of renewable technologies, the effect of a colonial relationship vanishes, while the effect of a common language in the case of fossil technologies is statistically not different from zero. Conditional on pre-sample transfer, geography does not affect patent applications between the sending and the receiving country.

The coefficient associated with the innovator's knowledge stock in the pre-sample mean model supports the finding in Acemoglu et al. (2012), pointing to a directed technical change effect. The more experienced is country *i* in technology s, the greater the likelihood of exporting blueprints of that specific technology. The resulting coefficients are however more than 3 times higher in the case of renewables as compared to efficient fossil patents. A 100 patents increase of the knowledge stock increases the probability of bilateral renewable transfer by around 0.8% (exp(0.00784)) whereas the corresponding effect in the case of fossil patents is lower than 0.2% (exp(0.00216)). The estimates from the pre-sample mean model under the assumption of regressors' exogeneity are more than one order of magnitude lower in the case of fossil technologies, and about three fourths lower in the case of renewable technologies. This indicates that the pooled Poisson model results are biased upwards, as they confound the true effect of the sending country's knowledge stock with the effect of unobserved pair heterogeneity.

We now turn to the characteristics of the receiving market. Market size, measured by electricity consumption in TWh at time *t-1*, positively affects technology transfer. Moreover, the likelihood that foreign inventors will apply for a patent in the domestic market is positively correlated with our proxy for the recipients' absorptive capacity (own innovation effort). The effect is stronger in the case of renewable technologies. This results seems to rule out the hypothesis of a crowding-out effect, pointing rather to a crowd-in effect of own innovation. This result is in line with a rich macro and micro literature pointing to the role of absorptive capacity in attracting innovation (Cohen and Levinthal [1990], Griffith, Redding and Van Reenen [2003], Keller [1996]). For both such variables, estimated coefficients are biased upwards if unobserved heterogeneity is not accounted for.

The coefficient associated with the rule of law indicator in specifications (R2) and (F2) is positive in both the renewable and fossil specifications, although it is around three times higher for the former. Specifically, a one point increase in the Rule of Law indicators (which is equivalent to 1%) increases the probability of transfer by roughly 0.5% (exp(0.00458)) and 0.1% (exp(0.00173)) for renewables and fossil efficient technologies, respectively. This result is in line with Barro (2003), who finds a positive relationship between Rule of Law and economic growth. Moreover, it suggests that one of the channels through which law enforcement contributes to economic growth is its positive effect on technology diffusion and transfer. As a result, the receiving country moves closer to the technological frontier and arguably improves production efficiency. Once again, comparing the GMM estimates with the Pooled Poisson model, it is apparent that controlling for unobservable fixed effects corrects for upward.

Turning now to the variables of interest, namely IPR and environmental policy, results confirm expectations. A higher level of IPR protection is associated with higher bilateral technology transfer. The square IPR term has a negative and significant coefficient, indicating that there are, indeed, diminishing marginal returns to stricter IPR protection, but that they are small. A 1% increase in the Ginarte and Park index is associated with a probability of transfer 7.5% and 5.1% higher for renewable and fossil blueprints, respectively.

With respect to environmental policy, the estimates of the pre-sample mean model under the assumption of regressors exogeneity imply that the marginal benefit of an additional policy increases the probability of bilateral transfer by 1.1% (exp(0.0105)) and 1.3% (exp(0.0125)) for renewable and fossil technologies, respectively. Conversely, an increase in the width of policy portfolio measured as the addition of one policy instrument increases the probability of bilateral transfer by 2% (exp(0.019)) and 4% (exp(0.0398)).

The general conclusion emerging from a comparison of the GMM estimates with those of the Poisson model is that not accounting for observed heterogeneity results in significantly different point estimates on most model variables. In the GMM estimation with pre-sample mean, the coefficients associated with some variables maintain the same sign but are significantly smaller than those emerging from the Poisson model (for example, for the language dummy and the innovator's knowledge stock variable). Other coefficients which reach acceptable levels of significance in the Poisson estimation are statistically not significant from zero in the GMM estimation (for example, colonial relationship and distance).

5 Instrumental variable estimation

We need to address two major concerns regarding our policy indicators, as discussed in Section 3. First, if the regressors, and particularly the policy variables, are not truly exogenous, the coefficients presented in the previous Section are biased. Endogeneity arises from unobservables affecting both the policy indices and the dependent variable, as well as from feedbacks between the two policy indices themselves. Second, the bias in the coefficient which is linked with the endogeneity of the policy indicators is further complicated by issues related to measurement error. Therefore, it is hard to state a priori if an instrumental variable approach will likely change the magnitude of the estimated coefficients in one direction or the other.

To address the measurement error and the endogeneity of the policy indices, we select a vector of both in-sample and out-of-sample instruments and re-estimate our model with an IV approach. Lagged values of the policy indices are good candidate instruments for current values under the weak exogeneity assumption, namely that past values are not correlated with current shocks. This is also true if current values of the explanatory variables are measured with error, under the assumption that the measurement errors are not serially correlated. We use one-period-lagged policy variables to instrument under the assumption that past values of the policy variables are positively correlated with current levels.

We also select two additional instruments which do not directly affect the level of transfer of renewable and fossil blueprints, but are likely correlated with both the quality of the IPR regime and a country's commitment to environmental policy. The likelihood of committing to cleaner and more efficient electricity production and to stronger IPRs is likely influenced by public opinion and citizens' support.

To capture this effect, we select a first indicator measuring the length of the democratic system in receiving country j. This indicator has been previously suggested as an instrument in the literature (Nesta , Vona and Nicolli 2012) under the assumptions that democratic countries tend to display higher levels of policy stringency and that long-lasting democratic governments are more responsive to citizens' preferences. This assumption is validated by a large number of previous studies. Grossman and Krueger (1995), Fredriksson et al. (2005) and Ward (2008) among others have shown that democratic regimes are more likely to commit to strict environmental policy. Democracies are also characterized by a system of check and balances and majority ruling. North (2000) and Olson (2003), for example, argue that democratic systems are more likely to enforce well-designed property rights regimes to avoid that individuals with superior coercive power enforce the rules to their advantage and infringe the rights of fellow citizens. The older a democracy, the more stringent the IPR system and the higher the commitment to environmental policy.

A second indicator we construct is based on information regarding the occurrence of environmentally-related disasters in the receiving country at any point in time. The data we rely on includes information on occurrences and costs associated with droughts, extreme temperatures, floods, storms or wildfires (EM-DAT [2012]). Such events, more than any other significant discoveries or pieces of scientific evidence, are likely to affect individuals' collection of samples of environment-related problems, thus feeding availability biases. By increasing the perceived likelihood of negative environmental events, natural disasters positively affect the demand for environmental policies. This is in line with what is found concerning self-protecting behaviors in the case, for example, of insurance expenditures (Kunreuther et al. [1978]).

As such, environment-related disasters are expected to be positively correlated with the environmental policy indices. We build an indicator equal to 1 if the recipient country has borne the costs associated with such events at time t-3 and use this as an instrument in our regression. We allow for 3 lags to account for the longer term effect of environmental disasters on policy commitment.[23]

Our expectations with respect to the effect of out-of-sample instrumental variables are supported by examining auxiliary reduced form regressions of both policy indices on the instruments, which are displayed in the Supplementary Table II. The variable measuring the length of a democratic system has a positive and significant coefficient both with respect to the level of IPR protection and to the indices of environmental policy. Conversely, the dummy indicating the presence of natural disasters has a positive and significant coefficient in the environmental policy indices specifications, but no effect on IPR protection.

Conditional on our exclusion restrictions being valid, we carry out an exogeneity test of the policy indices as suggested by Woolridge (2002). Specifically, we regress the policy indices on the full

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[23] EM-DAT (2012) also includes information about the size of economic losses associated with each of these occurrences. We rely instead on the dummy variable indicator as the size of economic losses is conditional on the country's size of the economy and on calculations related to the value of statistical lives, etc.

set of exogenous regressors and instruments, and include the residuals from the first stage regressions in the pre-sample mean GMM model. Testing the significance of the coefficients associated with the residual terms, we can reject the null hypothesis that they are different from zero. We thus confirm that our policy indices suffer from endogeneity bias.

We then re-estimate model (10) with the full set of instruments described above. The estimated results under the assumption of IPR and environmental policy endogeneity are presented in Table III, specifications R3 and F3. The point estimated coefficients with all vectors of instruments and for both technologies are generally in line with the ones presented above, with the exception of the variable proxying for the number of environmental policy instruments in the renewable specification, which is smaller in size, and fails to reach acceptable levels of. According to the Hansen's J test of over-identifying restriction, we cannot reject the null hypothesis that the chosen instruments are valid, supporting our IV strategy.

A final specification we propose (columns R4 and F4) includes the interaction between the two EPs indices, to explore for the presence of any compound effect. While the coefficients associated with all other variables in these specifications are in line with previous results, the coefficients of the two environmental policy indices now increase in size. They are about 3 times higher in the case of renewables and twice as high in the case of efficient fossil technologies and statistically significant in both specifications. Moreover, the coefficient associated with the interaction term is negative, but statistically significant only in the case of renewable patents. This suggests that the benefit of additional environmental commitment by means of an additional policy instrument has diminishing marginal returns.

To further explore if any particular category of environmental policy instrument drives the empirical results, we re-estimate the models including three different indicators, under the assumption of policy endogeneity (Table IV). The three indices measure the breadth of the policy portfolio in each of the three subcategories, namely Market-Based (specifications R5 and F5), Command-and-Control (specifications R6 and F6) and Technology (specifications R7 and F7).

[Table IV around here]

The estimated coefficients associated with all other control variables are in line with what presented in Table III. Regarding the environmental policy indices, note that market-based measures are the ones which are associated with a positive effect on bilateral technology transfer in the case of renewable technologies. MB instruments, in the form of subsidies, feed-in tariffs or financial instruments constitute a powerful incentive for foreign patent holders, as they provide not only a clear signal of commitment to cleaner power production, but they also increase the monetary rents of the inventors (or, alternatively, they lower the comparative costs of producing power with renewable energy sources). Conversely, in the case of efficient fossil blueprints, the bilateral transfer of technology increases in the case of higher commitment to technology policy and R&D investment specific to the power sector, as the signaling effect of a growing market and of absorption capacity clearly prevails on the crowding out effect.

6 Conclusions

This paper investigates how domestic policies influence the incoming transfer of clean and dirty technologies from top innovator countries. Focusing on these two different technological options is important because the sustainable growth implications of diffusion differ dramatically in the two cases. We present a two sector (“clean” and “dirty”) model of transfer identifying those characteristics in the sending and in the receiving country which affect the transfer of technological know-how. The model shows that the transfer of clean and efficient frontier technologies from abroad is an increasing function of the sending country’s innovative ability, of the receiving country’s size and its ability to enforce the law. Conversely, it is negatively affected by all factors which increase the fixed and variable costs of technology transfer.

We use bilateral patent applications as a proxy of technology transfer because patents allow distinguishing between clean and dirty technologies. We thus complement and enlarge previous results which focus on other channels of transfer, such as trade or FDI. We empirically test the model's prediction focusing on the sector of power production in a sample of 13 top innovating OECD countries and 40 receiving countries because of the relevance of this sector with respect to sustainable growth, energy security and climate change challenges.

The empirical analysis we present focuses on estimating the effect of two largely debated policies. On one hand, IPR protection addresses the innovation externality. On the other hand, environmental policy protection internalizes environmental externalities. Results of a GMM estimation, which accounts for both unobserved heterogeneity and the endogeneity of our policy variables, confirms the positive relationship between transfer and the sending country's innovative ability, on one hand, and the receiving country's market size and absorptive capacity, on the other hand.

We show that countries whose property rights protection and ability to enforce the law are higher are able to attract more foreign clean and efficient technologies. This positive effect is slightly greater for the less mature technology (renewables), indicating that in this case an increase in the protection of property rights and rule of law goes a great deal towards reducing the high uncertainty associated with technology transfer for frontier technological options.

Moreover, countries which commit to higher environmental policy protection both by implementing more environmental laws and by increasing the size of the policy instrument portfolio are more attractive markets for the transfer of foreign clean and efficient technologies. However, environmental policy per se does not necessarily favor the transfer of renewables (less mature, but cleaner) technologies more than the transfer of more efficient fossil-based (and carbon-emitting) power technologies.

This likely depends on the fact that efficient fossil technologies have lower costs of production than clean technologies and might be more attractive for many receiving countries because they do not require a paradigm shift in energy production. This could also be the result of complementaries between clean and dirty technologies, which is due to their different implied flexibility in meeting variable power demand. Our evidence thus suggests that in the sector of power production environmental policy *per se* does not lead to a switch in the type of technology transferred (renewable vs fossil efficient), although it favors the diffusion of generally less polluting technologies.

Looking at the effect of the different policy instruments, fiscal incentives are associated with a higher transfer of renewable technologies. Conversely, a positive effect is found in the case of technology policies supporting R&D and deployment in the case of fossil efficient technologies. Finally, command and control policy instruments do not have a discernible effect on the inflow of foreign technology, be it renewable or fossil efficient. This last result is in line with a rich theoretical literature which points to the dynamic inefficiency of C&C instruments for innovation. The evidence we present shows that C&C policy instrument are inefficient also with respect to the transfer and diffusion of foreign superior technologies.

Our results are of great relevance for the policy making community. Countries off the technological frontier, for which foreign innovation represents a great opportunity to catch up, should carefully draft their IPR and environmental policy not only to promote the strengthening of the domestic research sector, but also to become attractive destination markets for foreign technologies. The choice regarding the type of environmental policy instrument put in place should take into account the effect that market-based, command-and-control or technology policy instrument have on the likelihood of foreign clean and dirty technology transfer.

On a final note, this paper does not address the welfare implications emerging from our presented results (Branstetter, Fishman and Foley [2006]). We cannot comment on whether an IPR reform or the introduction of environmental policies have a positive or a negative effect on the overall welfare of the research sector, the producers or the consumers in the receiving countries. Rather, we show that domestic policies affect the diffusion and transfer of foreign innovation.

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Supplementary Data

Supplementary Table I. IPC Codes for renewable and efficiency improving fossil fuel technologies for electricity generation

COAL GASIFICATION	
C10J3	Production of combustible gases containing carbon monoxide from solid carbonaceous fuels
COAL DRYING	
F26B	Drying solid materials or objects by removing liquid therefrom
F26B	Drying solid materials or objects by removing liquid therefrom (exclude combinations with A, B and D)
F26B	Drying solid materials or objects by removing liquid therefrom (with combinations with classes A, B and D)
C10B 47	Destructive distillation of solid carbonaceous materials with indirect heating, e.g. by external combustion
C10B 49	Destructive distillation of solid carbonaceous materials by direct heating with heat-carrying agents including the partial combustion of the solid material to be treated
C10B 51	Destructive distillation of solid carbonaceous materials by combined direct and indirect heating
C10B 53	Destructive distillation, specially adapted for particular solid raw materials or solid raw materials in special form (wet carbonising of peat C10F)
C10B 55	Coking mineral oils, bitumen, tar or the like, or mixtures thereof, with solid carbonaceous materials (cracking oils C10G)
C10B 57	Other carbonising or coking processes; Features of destructive distillation processes in general
COAL PULVERIZATION	
B02C	Crushing, pulverising, or disintegrating in general; milling grain
B02C 1/00-14	Crushing or disintegrating by reciprocating members
B02C 2/00-10	Crushing or disintegrating by gyratory or cone crushers
B02C 4/00-02	Crushing or disintegrating by roller mills (with milling members in the form of rollers or balls co-operating with rings or discs B02C 15/00; roller mills or roll refiners exclusively for chocolate A23G 1/10, A23G 1/12)
B02C 4/08-12	· · with co-operating corrugated or toothed crushing-rollers
B02C 4/18	· · in the form of a bar
B02C 4/20	· · · wherein the roller is corrugated or toothec
B02C 4/26-34	· · in the form of a grid or grating
B02C 4/40-44	· · Detachers, e.g. scrapers
B02C 7/00-17	Crushing or disintegrating by disc mills
B02C 13/00-31	Disintegrating by mills having rotary beater elements
B02C 15/00-16	Disintegrating by milling members in the form of rollers or balls co-operating with rings or discs
B02C 17/00-24	Disintegrating by tumbling mills, i.e. mills having a container charged with the material to be disintegrated with or without special disintegrating members such as pebbles or balls (high-speed drum mills B02C 19/11)
B02C 23/00-40	Disintegrating by tumbling mills, i.e. mills having a container charged with the material to be disintegrated with or without special disintegrating members such as pebbles or balls (high-speed drum mills B02C 19/11)
B02C 25/00	Disintegrating by tumbling mills, i.e. mills having a container charged with the material to be disintegrated with or without special disintegrating members such as pebbles or balls (high-speed drum mills B02C 19/11)
IMPROVED BURNERS	
F23C1 not B60, B68, F24, F27	Combustion apparatus specially adapted for combustion of two or more kinds of fuel simultaneously or alternately, at least one kind of fuel being fluent
F23C5/24 not B60, B68, F24, F27	Combustion apparatus characterized by the arrangement or mounting of burners; Disposition of burners to obtain a loop flame.
F23C6 not B60, B68, F24, F27	Combustion apparatus characterized by the combination of two or more combustion chambers (using fluent fuel)
F23B10 not B60, B68, F24, F27	Combustion apparatus characterized by the combination of two or more combustion chambers (using only solid fuel)
F23B30 not B60, B68, F24, F27	Combustion apparatus with driven means for agitating the burning fuel; Combustion apparatus with driven means for advancing the burning fuel through the combustion chamber
F23B70 not B60, B68, F24, F27	Combustion apparatus characterized by means for returning solid combustion residues to the combustion chamber

F23B80 not B60, B68, F24, F27	Combustion apparatus characterized by means creating a distinct flow path for flue gases or for non-combusted gases given off by the fuel
F23D1 not B60, B68, F24, F27	Burners for combustion of pulverulent fuel
F23D7 not B60, B68, F24, F27	Burners in which drops of liquid fuel impinge on a surface
F23D17 not B60, B68, F24, F27	Burners for combustion simultaneously or alternatively of gaseous or liquid or pulverulent fuel
FLUIDIZED BED COMBUSTION	
B01J8/20-22	Chemical or physical processes (and apparatus therefor) conducted in the presence of fluidized particles, with liquid as a fluidizing medium
B01J8/24-30	Chemical or physical processes (and apparatus therefor) conducted in the presence of fluidized particles, according to “fluidized-bed” technique
F27B15	Fluidized-bed furnaces; Other furnaces using or treating finely-divided materials in dispersion
F23C10	Apparatus in which combustion takes place in a fluidized bed of fuel or other particles
IMPROVED BOILERS FOR STEAM GENERATION	
F22B31	Modifications of boiler construction, or of tube systems, dependent on installation of combustion apparatus; Arrangements or dispositions of combustion apparatus
F22B33/14-16	Steam generation plants, e.g. comprising steam boilers of different types in mutual association; Combinations of low- and high-pressure boilers
IMPROVED STEAM ENGINES	
F01K3	Plants characterized by the use of steam or heat accumulators, or intermediate steam heaters, therein
F01K5	Plants characterized by use of means for storing steam in an alkali to increase steam pressure, e.g. of Honigmann or Koenemann type
F01K23	Plants characterized by more than one engine delivering power external to the plant, the engines being driven by different fluids
SUPERHEATERS	
F22G	Superheating of steam
IMPROVED GAS TURBINES	
F02C7/08-105	Gas turbine plants - Heating air supply before combustion, e.g. by exhaust gases
F02C7/12-143	Cooling of gas turbine plants
F02C7/30	Gas turbine plants - Preventing corrosion in gas-swept spaces
COMBINED CYCLES	
F01K23/02-10	Plants characterized by more than one engine delivering power external to the plant, the engines being driven by different fluids; the engine cycles being thermally coupled
F02C3/20-36	Gas turbine plants characterized by the use of combustion products as the working fuel
F02C6/10-12	Combinations of gas-turbine plants with other apparatus; Supplying working fluid to a user, e.g. a chemical process, which returns working fluid to a turbine of the plant
F23R	Generating combustion products of high pressure or high velocity, e.g. gas turbine combustion chambers.
IMPROVED COMPRESSED-IGNITION ENGINES	
F02B1/12-14 not B60, B68, F24, F27	Engines characterized by fuel-air mixture compression ignition
F02B3/06-10 not B60, B68, F24, F27	Engines characterized by air compression and subsequent fuel addition; with compression ignition
F02B7 not B60, B68, F24, F27	Engines characterized by the fuel-air charge being ignited by compression ignition of an additional fuel
F02B11 not B60, B68, F24, F27	Engines characterized by both fuel-air mixture compression and air compression, or characterised by both positive ignition and compression ignition, e.g. in different cylinders
F02B13/02-04 not B60, B68, F24, F27	Engines characterized by the introduction of liquid fuel into cylinders by use of auxiliary fluid; Compression ignition engines using air or gas for blowing fuel into compressed air in cylinder
F02B49 not B60, B68, F24, F27	Methods of operating air-compressing compression-ignition engines involving introduction of small quantities of fuel in the form of a fine mist into the air in the engine’s intake.
COGENERATION	
F01K17/02	Using steam or condensate extracted or exhausted from steam engine plant, (...) for heating purposes
F01K17/06	Use of steam or condensate extracted or exhausted from steam engine plant; Returning energy of steam, in exchanged form, to process, e.g. use of exhaust steam for drying solid fuel of plant
F01K27	Plants for converting heat or fluid energy into mechanical energy

F02C6/18	Using the waste heat of gas-turbine plants outside the plants themselves, e.g. gas-turbine power heat plants
F02G5	Profiting from waste heat of combustion engines
F25B27/02	Machines, plant, or systems using waste heat, e.g. from internal-combustion engines

WIND	
F03D 1/00-06	Wind motors with rotation axis substantially in wind direction
F03D 3/00-06	Wind motors with rotation axis substantially at right angle to wind direction
F03D 5/00-06	Other wind motors
F03D 7/00-06	Controlling wind motors
F03D 9/00-02	Adaptations of wind motors for special use;
F03D 11/00-04	Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass
B60L 8/00	Electric propulsion with power supply from force of nature, e.g. sun, wind
B63H 13/00	Effecting propulsion by wind motors driving water-engaging propulsive elements
SOLAR	
F03G 6/00-06	Devices for producing mechanical power from solar energy
F24J 2/00	Use of solar heat, e.g. solar heat collectors
F26B 3/28	Drying solid materials or objects by processes involving the application of heat by radiation -e.g. sun
H01L 27/142	Devices consisting of a plurality of semiconductor componenets sentive to infra-red radiation, light -- expecially adapted foor the conversion of the energy of such radiation into electrical energy
H01L 31	Semi conductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wave lenght, or corpuscolar radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electridcal energy by such radiation
B64G 1/44	Cosmonautic vehicles..arrangements or adaptation for propulsion systems using raiation, eg deployable solar arrays
H01G 9/20	Electrolytic capacitors, rectifiers, detectors, switching devices, light-sensitive or temperature-sensitive devices; processes of their manufacture…light-sensitive devices
H02N 6/00	Generators in which light radiation is directly converted into electrical energy
E04D 13/18	Aspects of roofing for the collection of energy – i.e. solar panels
B60K 16/00	Arrangement or mounting of propulsion units not provided for in one of main groups B60K 1/00-B60K 7/00 [5]
H01L 25/00	Assemblies consisting of a plurality of individual semiconductor or other solid state devices (devices consisting of a plurality of solid state components formed in or on a common substrate H01L 27/00; assemblies of photoelectronic cells H01L 31/042
H01L 25/04	Assemblies consisting of a plurality of individual semiconductor or other solid state devices (devices consisting of a plurality of solid state components formed in or on a common substrate H01L 27/00; assemblies of photoelectronic cells H01L 31/042) … the devices not having a separate container
GEOTHERMAL	
F24J 3/00-08	Other production or use of heat, not derived from combustion - using natural or geothermal heat
F03G 4/00-06	Devices for producing mechanical power from geothermal energy
F03G 7/04	Mechanical-power producing mechanisms -- using pressure differences or thermal differences occurring in nature
H02N 10/00	Electric motors using thermal effects
OCEAN	
E02B 9/08	Tide or wave power plants
F03B 13/10-24	Submerged units incorporating electric generators or motors characterized by using wave or tide energy
F03G 7/04-05	Mechanical-power producing mechanisms - ocean thermal energy conversion
HYDROP POWER	
E02B 9/00-06 not E02B9/08	Water-power plants
F03B 13/06-08 not F03B 13/10-26	Submerged units incorporating electric generators or motors characterized by using wave or tide energy
F03B 3 not F03B 13/10-26	Machines or engines of reaction type (i.e. hydraulic turbines)
F03B 7 not F03B 13/10-26	Water wheels
F03B 15 not F03B 13/10-26	Controlling machines or engines for liquids

BIOMASS AND WASTE	
C10L 5/40-48	Solid fuels based on materials of non-mineral origin - animal or vegetable substances,; sewage, town or house refuse; industrial resides or waste materials
C10L 1/14	Liquid carbonaceous fuels; Gaseous fuels; Solid fuels
F02B 43/08	Engines operating on gaseous fuels from solid fuel - e.g. wood
B01J 41/16	Anion exchange - use of materials, cellulose or wood
C10B 53/02	Destructive distillation, specially adapted for particular solid raw materials or solid raw materials in special form (wet carbonising of peat C10F)
F23G 7/0*	Methods or apparatus, e.g. incenerators, specially adapted for combustion of specific waste or low grade gfuelss, e.g. chemicals … of field or garden waste
F23G 7/1*	Methods or apparatus, e.g. incenerators, specially adapted for combustion of specific waste or low grade gfuelss, e.g. chemicals … of field or garden waste
C10L 1 and (F23G5 or F23G7)	Liquid carbonaceous fuels
C10L 3 and (F23G5 or F23G7)	Gaseous fuels; Natural gas; synthetic natural gas obtained by proceesed not voered by subcallses C10G, C10K; liquefied petroleum gas.
C10L 5 and (F23G5 or F23G7)	Solid fuels
B09B 1 and (F23G5 or F23G7)	Destroying solid waste or transforming solid waster into something useful or harmless
B09B 3 and (F23G5 or F23G7)	Incineration of waste; Inceneration constructions

Supplementary Table II: Instrumental variable estimation, auxiliary first stage regressions

	Count of Policies j	Policy Portfolio's Width j	IPR
Length Democracy	0.118***	0.0310***	0.251***
	[0.00371]	[0.00110]	[0.00792]
Natural Disasters	0.726***	0.185***	0.452
	[0.156]	[0.0463]	[0.334]
Observations	8,626	8,626	8,626
R-squared	0.616	0.591	0.567
F-test	506.9	400.4	502.0
Prob > F-test	0	0	0

Notes: regressors in auxiliary models include all exogenous variables, the two out-of-sample instruments and time fixed effects. *, ** and * indicate levels of significance at 10%, 5% and 1%, respectively.**

Tables

Table I. Innovation and transfer from top OECD innovators, 1990-2007

	Renewables			**Fossil**		
Inventor Country	**New Blueprints**	**Duplicates**	**Avg Duplication**	**New Blueprints**	**Duplicates**	**Avg Duplication**
AT	455	833	1,83	567	1.049	1,85
CA	355	716	2,02	1.003	1.159	1,16
CH	305	1.134	3,72	1.369	2.983	2,18
DE	4.177	7.193	1,72	10.159	9.448	0,93
ES	1.038	506	0,49	114	265	2,32
FI	378	536	1,42	628	1.983	3,16
FR	1.162	2.411	2,07	1.750	4.888	2,79
GB	2.070	3.216	1,55	963	2.696	2,80
IT	466	1.019	2,19	582	1.736	2,98
JP	7.090	10.278	1,45	3.253	6.511	2,00
NL	685	1.218	1,78	342	1.212	3,54
SE	444	812	1,83	610	1.503	2,46
US	7.028	10.934	1,56	6.860	17.596	2,57
Total	25.653	40.806	1,59	28.200	53.029	1,88

Table II: Variables description, empirical proxies and data sources.

Model Variable	Indicator	Data	Data Sources
Dependent Variable			
Tij	Patent Transfer	Count of patent applications from inventors in country i to application authority j	KITES Patent database
Explanatory Variables			
D_ij	Geographical Distance	Distance	CEPII
	Cultural Distance	Dummy variable for same language	
	Historical Ties	Dummy variable for colonial relationship	
M_j	Total Spending in receiving country	Total Power Consumption	WDI
F_j, C_j	Fixed and Variable costs of production in j	Policies targeting greener electricity production in receiving country	IEA World Energy Outlook Policy Database
		Rule of Law	ICRG
		Proxy for intellectual property rights in receiving country (and square)	Ginarte and Park (1998) and Park (2008)
		Absorptive Capacity of receiving country measured by innovation level (patents)	KITES Patent database
KO_i	Own Stock of innovating country (technology specific)	Patent Stock of own innovation, perpertual inventory method, initialized in 1975, discount rate 10%	KITES Patent database
ξ_ij	Observed (and unobserved) heterogeneity	Country dummmies or pre-sample mean as in Blundel et al. (2002)	KITES Patent database

Notes: Variables capture bilateral characteristics (ij), characteristics of the sending country (i), or characteristics of the receiving countries (j).

Table III: Estimation Results, baseline specifications

	(R1)	(R2)	(R3)	(R4)	(F1)	(F2)	(F3)	(F4)
	Pooled Poisson	Exogenous	Endogenous	Endogenous	Pooled Poisson	Exogenous	Endogenous	Endogenous
Own Stock (is)	0.0268***	0.00784**	0.00863***	0.0113***	0.0210***	0.00216**	0.00222***	0.00232***
	[0.00589]	[0.00330]	[0.00303]	[0.00310]	[0.00710]	[0.000878]	[0.000862]	[0.000899]
Common Language	0.295***	0.129**	0.119***	0.115**	0.440***	0.0711	0.0613	0.0622
	[0.0577]	[0.0507]	[0.0459]	[0.0489]	[0.0526]	[0.0463]	[0.0454]	[0.0455]
Distance (1,000 km)	-0.0470***	-0.00325	-0.00349	-0.00456*	-0.0583***	0.00372	0.00295	0.00211
	[0.00595]	[0.00271]	[0.00267]	[0.00262]	[0.00509]	[0.00288]	[0.00281]	[0.00273]
Colonial Relationship	0.260***	0.00158	0.00361	0.0343	0.0818	-0.147	-0.135	-0.130
	[0.0666]	[0.0529]	[0.0477]	[0.0490]	[0.0606]	[0.0955]	[0.0932]	[0.0919]
Market Size (j)	0.000904***	0.000218***	0.000228***	0.000226***	0.000672***	0.000181***	0.000182***	0.000183***
	[8.53e-05]	[3.77e-05]	[3.45e-05]	[3.32e-05]	[0.000113]	[2.35e-05]	[2.22e-05]	[2.27e-05]
Absorptive Capacity (js)	0.00178***	0.00102***	0.000984***	0.000958***	-7.75e-05	0.000146**	0.000131**	0.000101*
	[0.000200]	[0.000179]	[0.000139]	[0.000155]	[0.000154]	[6.44e-05]	[6.36e-05]	[5.69e-05]
Rule of Law (j)	0.00811***	0.00458***	0.00456***	0.00347***	0.00849***	0.00173*	0.00187**	0.00187**
	[0.00196]	[0.00151]	[0.00133]	[0.00129]	[0.00163]	[0.000926]	[0.000921]	[0.000942]
IPR (j)	0.0454***	0.0729***	0.0828***	0.0828***	0.0316***	0.0506***	0.0530***	0.0524***
	[0.00546]	[0.0148]	[0.0145]	[0.0150]	[0.00372]	[0.00565]	[0.00628]	[0.00626]
IPR squared (j)	-0.000416***	-0.000710***	-0.000776***	-0.000766***	-0.000296***	-0.000515***	-0.000534***	-0.000530***
	[5.10e-05]	[0.000109]	[0.000114]	[0.000117]	[3.82e-05]	[4.81e-05]	[5.28e-05]	[5.36e-05]
Stock of Policies (j)	0.00808***	0.0105**	0.0109***	0.0562***	0.0103***	0.0125***	0.0134***	0.0271**
	[0.00310]	[0.00409]	[0.00383]	[0.0181]	[0.00226]	[0.00342]	[0.00334]	[0.0133]
Number of Policy Instruments (j)	-0.0363*	0.0190*	0.0107	0.0418***	-0.00598	0.0398***	0.0346**	0.0440***
	[0.0185]	[0.0106]	[0.0137]	[0.0155]	[0.0120]	[0.0130]	[0.0140]	[0.0139]
Interaction Policy Indexes (j)				-0.00536**				-0.00175
				[0.00216]				[0.00151]
Pre Sample Mean	Country	0.933***	0.932***	0.903***	Country	0.942***	0.943***	0.940***
	dummies	[0.0225]	[0.0227]	[0.0247]	dummies	[0.0161]	[0.0161]	[0.0171]
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,376	8,376	8,376	8,376	8,626	8,626	8,626	8,626
Moments		30	32	33		30	32	33
Hansen's J Test			1.549	4.065			0.511	0.923
Significance Hansen's J Test			0.461	0.131			0.775	0.630

Notes: Dependent variable: patent applications in renewable (R1-R4) and efficient fossil technologies (F1-F4) from sending country *i* to receiving country *j*. Standard errors clustered at the country-pair level in parenthesis. Specification 1: Pooled Poisson Model with country dummies. Specification 2: pre-sample mean Poisson Model with GMM estimation, regressors' exogeneity. Specifications 3 and 4: pre-sample mean Poisson Models with GMM estimation, regressors' endogenity. Instruments: IPR and environmental policy indices lagged once, length of democratic system, presence of natural disasters in time t-3. All models include time fixed effects. Variables indicated by (s) are technology-specific. *, ** and * indicate levels of significance at 10%, 5% and 1%, respectively.**

Table IV: Estimation results, additional environmental policy indicators

	(R5) Endogenous Fiscal	(R6) Endogenous Regulatory	(R7) Endogenous Technology	(F5) Endogenous Fiscal	(F6) Endogenous Regulatory	(F7) Endogenous Technology
Own Stock (is)	0.00951***	0.00809***	0.00745**	0.00193**	0.00195**	0.00222**
	[0.00284]	[0.00303]	[0.00299]	[0.000941]	[0.000897]	[0.000892]
Market Size (j)	0.000219***	0.000220***	0.000214***	0.000173***	0.000169***	0.000180***
	[3.29e-05]	[3.47e-05]	[3.38e-05]	[2.25e-05]	[2.20e-05]	[2.18e-05]
Common Language	0.151***	0.116**	0.106**	0.0606	0.0534	0.0608
	[0.0505]	[0.0481]	[0.0432]	[0.0472]	[0.0461]	[0.0445]
Distance (1,000 km)	0.00197	-0.00338	-0.00336	0.00330	0.00205	0.00152
	[0.00289]	[0.00274]	[0.00263]	[0.00316]	[0.00291]	[0.00286]
Colonial Relationship	0.0264	0.00916	0.0155	-0.139	-0.134	-0.139
	[0.0427]	[0.0517]	[0.0463]	[0.0947]	[0.0946]	[0.0901]
Absorptive Capacity (js)	0.00113***	0.000995***	0.000987***	0.000125**	0.000159***	0.000146**
	[0.000152]	[0.000166]	[0.000163]	[6.03e-05]	[5.85e-05]	[6.17e-05]
Rule of Law (j)	0.00389***	0.00416**	0.00429***	0.00154	0.00192**	0.00191**
	[0.00136]	[0.00163]	[0.00128]	[0.000964]	[0.000960]	[0.000950]
IPR (j)	0.0833***	0.0802***	0.0820***	0.0499***	0.0506***	0.0506***
	[0.0133]	[0.0143]	[0.0145]	[0.00599]	[0.00578]	[0.00620]
IPR squared (j)	-0.000813***	-0.000736***	-0.000747***	-0.000495***	-0.000498***	-0.000506***
	[0.000105]	[0.000110]	[0.000112]	[4.99e-05]	[4.88e-05]	[5.00e-05]
Stock of Policies (j)	0.0118***	0.0109***	0.0124***	0.0140***	0.0142***	0.0123***
	[0.00353]	[0.00361]	[0.00372]	[0.00324]	[0.00312]	[0.00326]
Number Policy Instruments (j) Fiscal	0.172*** [0.0324]			0.0428 [0.0326]		
Number Policy Instruments (j) Regulatory		-0.0450 [0.0427]			0.0330 [0.0288]	
Number Policy Instruments (j) Technology			-0.0537 [0.0340]			0.0633*** [0.0242]
Pre Sample Mean	0.917***	0.936***	0.943***	0.948***	0.949***	0.944***
	[0.0220]	[0.0236]	[0.0220]	[0.0172]	[0.0160]	[0.0157]
Year FE	Yes	Yes	Yes			
Observations	8,376	8,376	8,376	8,626	8,626	8,626
nr moments	32	32	32	32	32	32
Hansen's J	1.154	1.488	1.267	0.723	0.881	1.252
pvalue J	0.562	0.475	0.531	0.696	0.644	0.535

Notes: Dependent variable: Patent applications in renewable (R6-R8) and efficient fossil technologies (F6-F8) from sending country *i* to receiving country *j*. Standard errors clustered at the country-pair level in parenthesis. All models are pre-sample mean Poisson models with GMM estimation and endogenous policy regressors. Instruments: IPR and environmental policy indices lagged once, length of democratic system, presence of natural disasters in time t-3. All models include time fixed effects. Variables indicated by (s) are technology-specific. *, ** and * indicate levels of significance at 10%, 5% and 1%, respectively.**