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Summary

This article examines the impact of environmental regulation within countries as well as regulatory distance between countries on international technology transfer. We employ a recently-assembled dataset of automobile emission standards and corresponding data on non-resident patent filing of automotive environmentally sound technologies (ESTs) in 49 countries between 1992 and 2007. Our analysis shows that an important factor shaping transfers is relative regulatory distance in that countries are more likely to receive newly-innovated technologies from source countries whose regulatory standards are "closer" to their own. Absolute stringency matters as well, consistent with conventional wisdom, although raising domestic environmental standards as such only leads to higher inflows of ESTs in developing countries. Novel to the literature, we show that regulatory standards in the third markets of a country's trading partners also influence transfers: countries receive more ESTs from a specific source country where they export more to markets whose regulatory standards are similar to those of the source country of the transferred technologies. As concerns both domestic regulation and regulation in a country's major export markets, it is therefore regulatory distance that matters most rather than absolute regulatory levels.

Keywords: Pollution Control Technologies, Environmental Regulation, International Technology Diffusion

JEL Classification: O33, Q53, Q55

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Regulatory distance and the transfer of new environmentally sound technologies: Evidence from the automobile sector

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Abstract

This article examines the impact of environmental regulation within countries as well as regulatory distance between countries on international technology transfer. We employ a recently-assembled dataset of automobile emission standards and corresponding data on non-resident patent filing of automotive environmentally sound technologies (ESTs) in 49 countries between 1992 and 2007. Our analysis shows that an important factor shaping transfers is relative regulatory distance in that countries are more likely to receive newly-innovated technologies from source countries whose regulatory standards are "closer" to their own. Absolute stringency matters as well, consistent with conventional wisdom, although raising domestic environmental standards as such only leads to higher inflows of ESTs in developing countries. Novel to the literature, we show that regulatory standards in the third markets of a country's trading partners also influence transfers: countries receive more ESTs from a specific source country where they export more to markets whose regulatory standards are similar to those of the source country of the transferred technologies. As concerns both domestic regulation and regulation in a country's major export markets, it is therefore regulatory distance that matters most rather than absolute regulatory levels.

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1. Introduction

Although recent debates have emphasized the importance of cross-border transfers of environmentally sound technology (EST)[1] (Stern 2007; Popp 2011; Sachs 2009), surprisingly little is known about the conditions under which such technologies are transferred from innovating to recipient countries. Our contribution in the present article examines the role that environmental regulation plays in the international transfer of newly-innovated ESTs.

Motivating our focus on environmental regulation is the fact that, along with intellectual property rights (IPRs), it is frequently mentioned as one of the most influential factors influencing green technology transfer (Tébar Less and McMillan 2005; Gallagher 2006; Perkins 2007; Ockwell et al. 2011). Another motivating factor is that while the existing literature has demonstrated a link between environmental regulation and green technological innovation (Jaffe and Palmer 1997; Newell et al. 1999; Popp 2002; Brunnermeier and Cohen 2003; Carrion-Flores and Innes 2010; Verdolini and Galeotti 2011), it has not always produced convincing insights into the assumed impact of environmental regulatory stringency on cross-border transfers of new ESTs. In part, this is because past studies have mostly relied on proxies of environmental regulation, and/or small country samples (Lanjouw and Mody 1996; Popp 2006). Equally important, the majority of previous studies have assumed an unambiguously positive relationship between environmental regulatory stringency and the transfer of environmentally sound technologies. However, as Haščič and Johnstone (2009) observe, a more relevant factor shaping transfers than absolute regulatory

[1] ESTs are defined by Agenda 21 as technologies which 'protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes.'

stringency in a potential recipient country may be its level of regulation *relative* to potential source[2] countries. The existing literature has also fallen short in ignoring the possibility that ESTs may be transferred in order to be incorporated into products destined for a recipient country's export markets, such that regulatory stringency in a country's major export markets may also impact inflows of ESTs.

Our work addresses all three issues. First, expanding on the sample used in several previous studies, our panel comprises 49 countries over the period 1992 to 2007. Moreover, we make use of a recently constructed dataset, which provides a common measure of the actual level of domestic automobile emission standards. Second, as well as absolute levels of regulatory stringency, we examine how "regulatory distance" affects the transfer of newly-innovated ESTs between country dyads. Third, novel to the literature, we develop and subsequently test the thesis that third markets drive the transfer of newly-innovated technologies. More specifically, we explore the hypothesis that part of the impact of environmental regulation on transfers of innovative technologies has nothing to do with recipient country standards, but is determined by the regulatory distance between the domestic country's foreign export markets and the foreign source countries of innovations.

Consistent with the idea that regulatory distance influences the inter-country transfer of ESTs, we provide robust evidence that countries receive more newly-innovated technologies from source countries whose level of regulation is closer to their own. Absolute domestic stringency matters, but raising domestic standards would only appear to result in more inward transfers in developing countries. Furthermore, indicating that technologies are transferred in order to be incorporated into exported goods, countries receive more ESTs where a larger share of their automotive exports go

[2] Note, we use the terms source and inventor country interchangeably.

to markets whose regulatory standards are closer to those in the original source countries of transferred technologies.

2. Understanding the relationship between environmental regulation and transfer of ESTs

Environmental regulation provides a direct or indirect economic incentive for regulated parties to acquire compliance technology. The question addressed in the present paper is whether this regulation-induced demand is likely to stimulate the transfer of ESTs from abroad. In the case of regulatory frontrunners, i.e. those who lead in the introduction of the most stringent policy, it is quite likely that tighter domestic standards will be met through local innovative efforts rather than technology transfer (Porter and van der Linde 1995). As documented in the empirical literature, many ESTs have first been innovated within regulatory leader countries in response to domestic environmental standards, which have stimulated local demand for associated compliance technologies (Beise and Rennings 2005; Brandt and Svendsen 2006; Popp 2006).

However, once a particular compliance technology has been developed to comply with a specific standard, the adoption of similar environmental standards elsewhere may lead to its cross-border transfer (Beise and Rennings 2005; Huber 2008). Firms in early-regulating ("leader") source countries are likely to possess a competitive advantage vis-à-vis potential domestic competitors in later-regulating ("follower") countries, stemming from the fact that their pre-existing compliance technologies benefit from dynamic scale economies and learning effects (Brandt and Svendsen 2006). This, in turn, provides an incentive for owners/inventors in source countries to transfer their technologies to recipient countries who adopt similar standards to their own.

Importantly, differences between regulatory followers and leaders would suggest that the transfer of newly-innovated technologies will not be a simple positive function of regulatory stringency in the recipient country, with stricter regulations necessarily leading to higher inflows of ESTs from inventing countries. Instead, such transfers are likely to be greater where recipient country *j* adopts environmental standards similar to those in source country *i*, the economy in which the technology was originally designed to achieve compliance. That is, we expect the transfer of new ESTs to be a function of regulatory "distance" between sending and receiving countries, i.e. the gap between regulatory standards in *i* and *j*. A similar point is made by Haščič and Johnstone (2009) who invoke the idea of a "ladder" of increasingly costly ESTs capable of complying with more stringent environmental policies. According to the authors, individual countries' position on this ladder is determined by their domestic regulation, with technologies consistent with domestic firms' profit maximisation transferred from countries 'situated on the same rung of the ladder' (p. 3).

Taking this logic further, it would follow that the dynamic implications of domestic regulatory changes will depend on whether the level of regulation in the (potential) recipient country is higher or lower than the one in the (potential) source country. Specifically, where domestic environmental regulatory stringency in country *j* is lower than in country *i*, we expect regulatory tightening in the former closer to levels found in the latter to increase inward transfers. The underlying logic is that the adoption of more stringent standards will necessitate the uptake of compliance technologies in country *j* which can readily be supplied by firms in country *i* owing to their previous domestic experience of innovating to comply with these standards (Beise and Rennings 2005). Conversely, where standards in the (potential) recipient country are already higher than the ones in the (potential) source country *i*, i.e. on a higher rung of Haščič and Johnstone's (2009) regulatory ladder, a further regulatory tightening of standards in country *j* should lead to fewer transfers from *i* to *j*. Simply put, firms in country *i* are less likely to have innovated compliance technologies required to comply with standards which are more stringent than those required domestically, and will therefore be even less able to supply foreign demand in country *j*, as the regulatory distance between countries *i* and *j* increases further.

We therefore predict that:

H1. More newly-innovated ESTs will be transferred from source country i to recipient country j where the regulatory distance between the two countries is smaller.

Applied within a global context, this hypothesis would suggest that absolute regulatory tightening in countries which lag the major source countries of ESTs is likely to lead to higher total inward transfers, as the regulatory distance between the respective countries shrinks. These laggards will include developing countries, whose standards are invariably below those found in the major innovators of ESTs, which are all high-regulating developed economies. Conversely, for similar reasons of regulatory distance, the domestic tightening of environmental standards in countries which are at or higher than the level of regulation in major source countries is likely to lead to a reduction in transfers. This will inevitably mean frontrunner developed economies. In other words, the effect of domestic regulatory stringency on the *total* number of transfers of ESTs will depend on the relative regulatory position of countries, such that regulatory tightening will have different implications in regulatory leaders and followers. We explicitly test this logical extension from our first hypothesis in our empirical analysis.

While the idea that domestic environmental regulations should drive the transfer of ESTs across borders is far from novel, less widely entertained is the thesis that "foreign" environmental regulations in important trading partners may have a similar effect. Yet it is conceptually plausible. With the growth of international production networks and the spatial dispersion of supply chains across national borders, firms not only produce products for the domestic market, but also for export to foreign markets (Dicken 2010). What is more, export markets may have different environmental standards to those in the exporting country, possibly both more and less stringent. An important corollary is that ESTs may not only be transferred to comply with environmental standards in the domestic market, but also in order to be incorporated into products destined for export. To take one example: a parent company of a transnational automobile producer may transfer particular ESTs to a subsidiary in a lower-regulating country *j* so that its vehicles and components are capable of complying with environmental standards in its higher-regulating export market *k*. Entirely novel to the literature is our proposition that, as with regulatory distance between the foreign source country *i* and the recipient country *j*, what matters more than absolute stringency in foreign export markets *k* for transfers into country *j* is the regulatory distance between these export markets and the foreign source country *i*. This is because compliance technologies are developed to meet specific environmental regulatory standards and a likely source of these technologies will therefore be countries with similar standards to those in the recipient country's export markets, resulting in inflows from these countries.

We thus expect:

H2. *More newly-innovated ESTs will be transferred from source country i to recipient country j the smaller the regulatory distance between foreign markets k to which country j exports a larger share of its goods (affected by environmental regulations) on the one hand and inventor country i on the other hand.*

3. International technology transfer and the patent system

A patent is an exclusive property right granted by a state to an inventor for a limited period of time. Since a patent is only valid in jurisdictions where it is granted, inventors must file a patent with the competent authority in each of the countries where they wish to protect their technology, a process known as non-resident patent filing (NRPF) when these countries differ from the one of the inventor. NRPF has been widely used in recent years as a measure of the transfer of new technology from source to recipient countries (Dekker et al. 2010; Lanjouw and Mody 1996; Perkins and Neumayer 2011; Eaton and Kortum 1999; Popp et al. 2007; Dechezleprêtre et al. 2010; Chan 2010; Yang and Kuo 2007). [3] We follow a similar approach in the present paper, using the number of patents invented in country *i* and patented in country *j* as an indicator of the number of inventions transferred from country *i* to country *j*.

Once an invention has been patented in a country, the inventor can file the same patent in other countries up to 18 months after the initial patent application, or 30 months by going through the Patent Cooperation Treaty system. This means that technology transfer through the patent system only covers recently-innovated

[3] Another popular approach to examining the diffusion of technology is through the use of patent citations data (e.g. Verdolini and Galeotti 2011), although this is better suited to identifying cross-border knowledge spillovers than technology transfer via market transactions.

technologies and not older ones. Within the context of the present study, this characteristic of the patent system is a virtue, in that we are more concerned in the transfer of the latest ESTs rather than more vintage ones.

Using NRPF as an indicator of technology transfer is nevertheless not without limitations. First, not all inventions are patented, although there are very few examples of economically significant inventions that have not been patented (Dernis and Guellec 2000). The value of individual patents is also heterogeneous. However, this is less of an issue in the present paper to the extent that we focus on "exported" inventions, which are typically more valuable (Harhoff et al. 2003). Another limitation is that, although a patent grants the exclusive right to use a technology in a given country, we do not have any information on whether the technology has actually been used. Yet the high expense of patenting deters the filing for protection in countries where the technology is unlikely to be deployed. Filing a patent costs around €5,000 in Japan, €10,000 in the US and €30,000 at the European Patent Office (EPO) (Roland Berger 1995). Inventors are therefore unlikely to apply for patent protection in a particular economy unless they are relatively certain of the potential market value for the technology. Indeed, empirical evidence suggests that inventors do not patent widely and indiscriminately, with the average invention only patented in two countries (see Dechezleprêtre et al. 2011).[4]

4. Previous work

The existing empirical literature provides limited insights into the relationship between technology transfer and environmental regulation in the domestic country and its export markets. In one of the first studies of its kind, Lanjouw and Mody (1996) show that imports of pollution control equipment are correlated with environmental

[4] 75 per cent of inventions are patented in only one country.

regulatory stringency, as proxied by pollution abatement expenditure. Likewise, Popp et al. (2007) observe an increase in technology transfer from innovating countries in response to stricter environmental standards in the pulp and paper industry in Finland, Sweden and the US. Conversely, Popp (2006) finds that tighter air pollution standards in the US did not result in higher levels of innovation or transfers from Germany and Japan. Instead, demonstrating that ESTs may largely be developed in response to specific domestic standards, regulation-induced demand for compliance technologies was principally met through greater local innovative efforts.

The above three studies are based on essentially bivariate analyses of descriptive statistics. Moving to panel data studies with controls, for a sample of 66 states over the period 1990-2003, Dechezleprêtre et al. (2010) find that countries which ratified the Kyoto Protocol received more climate-friendly technologies from foreign inventors. Likewise, Dekker et al. (2010) show that signatories to the 1994 Oslo Protocol witnessed a large increase in NRPF of associated compliance technologies, both in the run-up and following the agreement. Yet, neither of these studies directly captures the stringency of particular environmental standards in countries, nor investigates how relative stringency between source and recipient countries affects technology transfer.

Evidence regarding the influence of exports on the transfer of technology is more limited still. Lanjouw and Mody (1996) provide descriptive statistics to support the idea that foreign patenting of pollution control technology in developing countries has been undertaken in order to protect owners' intellectual property in export markets. A number of qualitative case-studies also support the idea that exporting to foreign markets has induced the transfer of ESTs (Perkins 2007).

In sum, the existing literature provides some evidence that more stringent domestic environmental regulation is associated with more inflows of ESTs, although based on small country samples and/or proxies of actual standards. Only one past study has examined the influence of relative stringency on transfers, although the constituent regulatory measure used by the authors comprises broad greenhouse gas commitments, which themselves may correlate poorly with the stringency of actual mitigation policies across countries (Haščič and Johnstone 2009). To the best of our knowledge, no quantitative work has been undertaken to explore whether export markets impact inflows of ESTs, or how regulatory distance between these markets and the original source countries matters.

Our contribution seeks to address these shortcomings. To do so, we use the example of the automobile (i.e. passenger car) sector, which makes a good test-case for several reasons. First, a large number of countries have adopted tailpipe emission standards, with significant cross-national variations in regulatory stringency over the period of our study (Beise and Rennings 2005). The sector therefore lends itself to testing our hypotheses focusing on regulatory distance between countries. Second, complying with tailpipe emission standards is largely achieved through base-engine and after-treatment technologies, allowing us to examine the degree to which regulation drives the transfer of ESTs (Haščič et al. 2009; Perkins 2007; Gallagher 2006). Third, the automobile industry is a transnational assembly business in which automobiles and their constituent components are widely traded, and moreover between countries with different environmental standards. If exports do indeed drive the transfer of newly-innovated ESTs to (exporting) recipient countries, then it is likely that we should find evidence for these dynamics in the case of automobiles and automobile components.

Finally, we are able to test our hypotheses using large-sample, geographically and sectorally disaggregated data. Our dataset of automobile emission standards therefore provides a measure of actual regulatory stringency for a large number of developed and leading developing countries since the early 1990s. We also have data on the dyadic transfer of technologies required to comply with these standards. Additionally, our study employs sectorally disaggregated data on exports of automobiles and automobile components between country dyads.

5. Data

5.1. Patent data

Our data were obtained from the World Patent Statistical Database, otherwise known as PATSTAT, maintained by the European Patent Office (PATSTAT 2010). PATSTAT covers more than 80 patent offices worldwide and include over 60 million patent documents. We extracted all the patents filed in seven categories (fields) of automotive emissions abatement technology: air-fuel ratio devices; fuel injection technologies; catalytic converters and other post-combustion devices; positive crankcase ventilation systems; exhaust gas recirculation valves; on-board diagnostic systems; and oxygen, NO_x and temperature sensors. Relevant patent applications were determined using International Patent Classification (IPC) codes developed by the World Intellectual Property Organization (WIPO). In order to identify patents related to automotive emissions reduction technologies, we used IPC codes described by Haščič et al. (2009) and Vollebergh (2010). The list of IPC codes used in our analysis is provided in Annex 1.

Information about the patent office that receives the patent was used to identify countries to which a particular invention has been transferred. For patents filed at the European Patent Office we use the list of EPO member states designated in the patent application.[5] To identify the country where the technology was originally developed, we use information on the inventor's country of residence. Our final dataset comprises 372,414 patent applications filed in 49 countries. These countries are listed in Annex 2.

5.2 Automobile emission regulation data

Data for environmental standards governing maximum permissible levels of tailpipe emissions for pollutants from new automobiles were sourced from a dataset originally constructed by the authors (Perkins and Neumayer 2012). Because of restrictions imposed by the patent data, our final sample comprises 49 countries over the period 1992-2007. Countries' regulatory stringency is coded on a scale of 0 to 5. The basis of the classification scheme is the European Union's (EU) "Euro" emission standards which were originally implemented across member states in 1992 and have subsequently been tightened in a series of incremental steps. Countries are coded 0 if they had no national emissions standards in place for new vehicles, or if standards were less stringent than the equivalent[6] of Euro 1, during the year in question. Countries where Euro 1 or its equivalent was legally enforceable are coded 1, and so on, with 5 for countries having implemented the equivalent of the Euro 5 standard.

5.3 A first look at the data

Table 1 shows the top 10 inventor countries of end-of-pipe and process-integrated ESTs. As is common for other categories of environmental technologies (Dechezleprêtre

[5] Applicants filing a patent at the EPO must designate the European countries to which they intend to transfer the patent once granted by the EPO. This information is available in the PRS Legal Status database.

[6] Regulatory stringency in countries which have not specifically followed the EU (e.g. Japan and the US) were converted to the equivalent Euro standard, see Perkins and Neumayer's (2012).

et al. 2011), the pattern of inventive activity is highly concentrated, with just three developed economies (Japan, Germany and the US) accounting for 85 per cent of automotive EST patents over the period of our study. A further three OECD economies (South Korea, France and the UK) are responsible for another 8 per cent of the total stock of inventions. The share of resident patents filed by inventors domiciled in non-developed economies is small. China tops the list with 1.23 per cent of worldwide inventions of automotive ESTs, followed by Russia, Brazil and India with totals of 0.84, 0.13 and 0.12 per cent, respectively.

The same three countries which dominate innovation, i.e. Germany, Japan and the US, also dominate transfers, collectively accounting for more than 76 per cent of non-resident patent filings over the period of our study (see table 2). The main difference is that German inventors transfer a far greater share of their patented inventions than Japanese ones, with the result that Germany is the single most important source country for ESTs. The above three countries, together with France, the UK, Italy, Sweden and Austria, are responsible for 93 per cent of transfers. The recipients of these non-resident filings are far more diffuse, as shown in table 3. Yet, as with inventions and transfers, they are dominated by developed countries. Germany, the largest source of transferred ESTs, is also the largest recipient with 7.3 per cent of worldwide NRPFs. The US emerges as the seventh most important destination of non-resident filings but Japan only the twentieth. Between 1992 and 2007, only 11 per cent of EST transfers were from developed to non-developed countries, although this share has grown from 3 to 16 per cent over this period.

As shown in figures 1 and 2, respectively, our sample period is characterised by regulatory tightening in automobile emission standards across both developed (OECD) and developing (non-OECD) countries. As one would expect, developed economies have been regulatory frontrunners, while developing ones have been laggards.

6. Estimation framework

6.1 Baseline model specification: the effect of regulatory stringency

The number of technologies transferred from country *i* to country *j* in year *t* is measured by P_{ijt}, the number of patents filed in country *j* by inventors from country *i* in year *t*. We begin with a baseline model in which, consistent with conventional wisdom, it is assumed that absolute regulatory stringency in the recipient country determines inflows of ESTs from inventor countries. Our basic equation is thus as follows:

$$P_{ijt} = \alpha_1 REG_{jt-1} + \beta X_{ijt} + \varepsilon_{ijt} \qquad (1)$$

where REG_{jt} measures the stringency of the regulation in country *j*, X_{ijt} is a set of control variables that include, amongst others, a full set of country pair and year fixed effects, and ε_{ijt} is the error term.

6.2 An alternative model specification: the effect of regulatory distance

In order to examine the influence of relative stringency and test hypothesis H1, we define $REGDIST_{ijt}$, which captures the difference between the stringency of regulation in countries *i* and *j*. Formally, $REGDIST_{ijt} = abs(REG_{jt} - REG_{it})$ where REG_{it} and REG_{jt} denote the level of regulation in countries *i* and *j*, respectively, in year *t*.

We are centrally interested in the impact of a change in regulatory distance between country pairs on technology flows. Our specification incorporating distance is:

$$P_{ijt} = \alpha_1 REG_{jt-1} + \alpha_2 REGDIST_{ijt-1} + \beta X_{ijt} + \varepsilon_{ijt} \qquad (2)$$

6.3 Extending the model to account for exports

To test our second hypothesis that inflows of patented ESTs also depend on regulatory stringency in foreign economies to which a (potential) recipient country exports environmentally-relevant goods, we also account for the regulatory stringency in each recipient country's export markets. Our variable is constructed as the weighted mean of the regulatory stringency in all other countries *k*, with weights equal to the shares of the corresponding countries in the exporting country's exports of automobiles and automobile components. To calculate the weights, we compute average export shares during our entire sample period, using data from the United Nations's COMTRADE database (UN 2008). The weights are thus kept fixed over time in order to avoid endogeneity.[7] Consequently the variation in the export markets' regulatory variable only comes from variation in export markets' regulatory level. Let $REGEXP_{jt}$ be the weighted average regulatory stringency in country *j*'s export markets *k*. Formally, $REGEXP_{jt} = \sum_{k \neq j} \omega_{jk} REG_{kt}$ with $\omega_{jk} = \frac{X_{jk}}{\sum_{k \neq j} X_{jk}}$ where X_{jk} is the total amount of exports of automobile and automobile parts from country *j* to country *k* in our sample period.

For the model specification in which we estimate the effect of regulatory stringency (rather than regulatory distance), we estimate the following equation:

$$P_{ijt} = \alpha_1 REG_{jt-1} + \alpha_2 REGEXP_{jt-1} + \beta X_{ijt} + \varepsilon_{ijt} \quad (3)$$

Following a similar approach to the one used for domestic stringency, we also explore the impact of regulatory distance between the source country of transferred technologies and the recipient country's export markets in an alternative model

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[7] If changes in regulation change the export mix of the country, this feeds back into the weights, causing potential endogeneity.

specification. We define $REGDISTEXP_{ijt} = abs(REGEXP_{jt} - REG_{it})$, which leads us to estimate the following equation:

$$P_{ijt} = \alpha_1 REG_{jt-1} + \alpha_2 REGEXP_{jt-1} + \alpha_3 REGDIST_{ijt-1} + \alpha_4 REGDISTEXP_{ijt-1} + \beta\ X_{ijt} + \varepsilon_{ijt} \quad (4)$$

6.4 Control variables

We include five control variables. The first accounts for the number of relevant inventions within the field of automotive ESTs from the source country available for potential transfer. We measure this by $PAT_{i,t-1}$, comprising the number of inventions patented by inventors from country *i* anywhere in the world in year *t*-1, *and not previously patented*. Any invention patented in several countries is thus only counted once. We expect a positive effect of this variable on technology transfers from country *i* to country *j* because, all else equal, more non-resident patents should come from countries that have a higher number of technologies available to be patented in foreign economies.

A second control variable captures the stock of relevant patents previously filed in the recipient country *j*. The impact of this variable is theoretically ambiguous in that it could have a positive (complementary) or negative (substitutive) effect on transfers of patented technology from abroad. On the one hand, the stock of patents is a good proxy for local absorptive capabilities, which previous research has shown are critical for the diffusion of advanced technologies (see Saggi 2002). On the other hand, a high stock of patents may signal to foreign patent holders that the local market is already well-served by competing technologies, such that the economic payoff from having one's own innovation patented in this country is small. Following Peri (2005), the patent stock is calculated using the perpetual inventory method. Let $KPAT_{j,t-1}$ be the discounted stock of local inventions in country *j* at date *t*. We initialize patent stocks for the year 1950[8] by setting the initial value[9] at $K_{i,1950} = 0$ and use the following recursive formula for subsequent years:

$$KPAT_{j,t} = (1-\delta)KPAT_{j,t-1} + PAT_{j,t}$$

where PAT_{it} is the number of patents filed in country *i* in year *t*. The rate of depreciation of R&D capital, δ, is set at 15 per cent in our main estimations. We also check whether our results are robust to using 10 per cent and 20 per cent discount rates. Our patent stock variable is lagged by one year in the estimations in order to mitigate potential endogeneity problems.

As a third control variable, we include the number of relevant patents filed in country *j* by inventors from countries other than country *i*, denoted by $PAT_{-i,t}$. These patents cover technologies that are likely to compete with patents transferred by inventors from country *i*. A higher number of competing technologies may discourage transfers. Yet they might conversely attract more patents as firms in country *i* emulate their foreign competitors (Perkins and Neumayer 2011). Since inventors from country *i* are unable to observe patents simultaneously filed by inventors from other countries, we assume that they form expectations about the number of patents transferred from other countries in year *t* based on the number of patents transferred in *t*-1.[10] Using the

[8] One potential problem is that for some countries, such as China, our patent data only date back to 1985. However, given that we only start the regression analysis in 1992, this is unlikely to have a significant influence on the results.

[9] Setting the initial value of knowledge at 0 has a negligible influence on the results because we only start the regression analysis in 1992.

[10] Consistent with an adaptive expectations model, we also experimented with a distributed lag, but the data suggest that the best predictor of $PAT_{-i,t}$ is $PAT_{-i,t-1}$. Rational inventors should therefore use $PAT_{-i,t-1}$ to predict $PAT_{-i,t}$.

lagged value $PAT_{-i,t-1}$ also avoids a potential endogeneity issue that might arise because $PAT_{-i,t}$ is also a function of the regulatory level and regulatory distance.[11]

We further include a number of variables to control for factors unrelated to the automobile industry, but affecting general technology transfer between countries. To begin with, a measure of the degree of patent protection afforded by the recipient country is included. Several studies have shown that stricter patent laws have led to higher patent activity, e.g., Hall and Ziedonis (2001), Hu and Jefferson (2009), Lerner (2009) and Perkins and Neumayer (2011). We use Park's (2008) index of patent rights, which codes countries with values running from 0 (no protection at all) to 5 (highest protection). The data are interpolated to fill in gaps from missing years, but results are robust to using either the anterior or posterior value in time to impute missing rights protection values in a country.

In order to capture the general attractiveness of countries as locations to transfer and protect firms' technology, we use country *j*'s gross domestic product (GDP) and GDP per capita, with data taken from World Bank (2010). All else equal, larger and richer countries should attract more non-resident filings, including environmental-related ones (Perkins and Neumayer 2011). For example, larger countries are more likely to have a bigger automobile and automobile component manufacturing sector, leading to more inward transfers. We control for factors that are specific to each country pair but do not vary across time, such as language and spatial distance, by using country pair (dyad) fixed effects. Similarly, year specific fixed effects are used to control for trends that affect all countries equally, such as oil prices.

[11] In the robustness checks, we also use a two years lag of this variable.

6.5 Estimation technique and sample

Given the count nature of the dependent variable, i.e. the number of patents transferred, we use negative binomial regression in our main estimations. Our panel runs from 1992 to 2007.[12] Because we are interested in the cross-border transfer of technology, we consider only patents filed by non-residents in our estimations, e.g. a patent filed by a German inventor in the US. Our final dataset comprises a total of 405,678 NRPFs. Table 4 presents summary statistics for the variables used in the estimations.

7. Results

7.1 Main results

Our main estimation results are presented in table 5. Columns 1 and 2 show results from our baseline model specification (equations 1 and 3). We find that the domestic level of regulation in potential recipient country *j* has a statistically insignificant impact on patented technology transfers from foreign countries (column 1). That is, countries with more stringent tailpipe emissions standards have not received more inward transfers of automotive ESTs from innovating countries, a result which runs counter to conventional wisdom. We similarly find that absolute levels of stringency in a country's export markets do not statistically significantly affect transfers (column 2).

Columns 3 and 4 present results from the alternative model specifications given by equations (2) and (4). Rather than absolute regulatory stringency alone, these equations estimate the effect of regulatory distance, controlling for the level of absolute stringency. Consistent with hypothesis H1, column 3 shows that a statistically significantly negative relationship is estimated for our regulatory distance variable,

[12] 1992 is the first year for which we have data on environmental regulatory stringency, while 2007 is the last reliable year in the September 2010 version of the PATSTAT database.

indicating that the number of newly-innovated automotive ESTs transferred between countries increases when the difference between the two countries' regulatory levels decreases. At the sample mean, a decrease of regulatory distance between countries of one level on the Euro-equivalent scale (e.g. if the source country is currently at Euro 2 and the recipient moves from Euro 1 to 2) is estimated to increase the number of non-resident patents filed in the recipient country by 9.0 per cent.[13]

In column 4, we account for the regulatory stringency in the recipient country's export markets. Consistent with hypothesis H2, regulatory distance between the source country and the export markets of the recipient country has a negative and statistically significantly effect on the transfer of ESTs. Interestingly, the point estimate of the domestic regulatory distance decreases, suggesting that omitting the export markets' regulatory distance leads to an over-estimate of the impact of domestic regulation. Substantively, we find that an increase in the recipient country's domestic regulation by one point (on the Euro-equivalent scale) increases the number of automotive ESTs transferred to the recipient country by 4.8 per cent. A change in the regulatory level of the recipient country's export markets by one point, meanwhile, increases the number of patented technologies transferred to the recipient country by 9.9 per cent. One must keep in mind, however, that a one point change in the export markets' regulation would require a one point change in *all* export markets (on average). Hence, the marginal impact of a regulatory change in one export market is likely to be much smaller, and depends on the importance of this particular market for the recipient country.

Turning to controls, our variables capturing the number of patented automotive ESTs available to transfer ($PAT_{i,t-1}$) and GDP per capita are estimated as statistically significant with the anticipated positive sign. Likewise, both variables controlling for the

[13] In Poisson and negative binomial models the coefficient can be interpreted as a semi-elasticity.

pre-existing stock of relevant patents filed in the destination country ($KPAT_{j,t-1}$) and the prior number of patents filed in the destination country by inventors other than those from country *i* ($PAT_{-i,t-1}$) are statistically significantly positive. Yet neither the strength of intellectual property rights nor GDP emerge as statistically significant predictors of non-resident filings of automotive ESTs.

7.2 The specificity of developed-developing country flows

Much of the debate on technology transfer has focused on the transfer of ESTs from developed to developing countries (Ockwell et al. 2011; Gallagher 2006; IPCC 2007). In order to explore these flows, as an alternative to pooling all cross-country transfers, we examine whether the above findings hold when restricting the sample to non-resident patents filed by OECD country residents in non-OECD countries.

As shown in table 6, we find similarities, as well as major differences, to the main estimations. Absolute regulatory stringency now has a significantly positive impact on inflows of patented ESTs (column 1). The estimated effect becomes smaller when regulatory distance between countries *i* and *j* is included in the model (column 2), but it remains statistically significant. This shows that the effect of absolute stringency is not entirely determined by developing countries almost invariably lagging behind developed countries in emission standards. Regulatory distance continues to have a negative effect on the transfer of patented ESTs. Contrary to expectations, however, a smaller distance of regulation in a developing recipient country's major export markets to the regulation found in a source country does not increase EST transfers from this source country into the recipient country. Nor does absolute regulatory stringency in developing countries' major export markets matter for developed-developing country flows. One possible explanation for this result is that automobile-related exports from developing countries could be concentrated in technologies which are unrelated to tailpipe emissions, meaning that trade does not generate the need for significant imports of compliance technologies.

7.3 Consequences for total transfers

A key finding to emerge from section 7.1 is that the transfer of ESTs is influenced by relative environmental regulatory stringency in country pairs. In particular, our results strongly indicate that an increase in regulatory stringency will raise patent inflows from countries to which the recipient moves closer, but decrease them from countries that end up further away. What this suggests is that the impact of absolute regulatory stringency on the *total* number of patents transferred into country *j* in year *t* is a priori ambiguous and will depend on the country's regulatory position relative to the rest of the world.

We now turn our attention to this issue, which is of primary interest to policy makers, particularly as concerns total transfers of ESTs to developing countries. To do so, we move away from a dyadic estimation framework to a monadic cross-country time-series panel, allowing us to directly analyze the effect of regulation on total transfers rather than dyadic transfers. Of course, one would expect the results from the monadic framework to be consistent with the ones from the dyadic framework if both are properly specified. We define P_{jt} as the total number of patents received by country *j* in year *t* from countries *i*, $i \neq j$: $P_{jt} = \sum_{i \neq j} P_{ijt}$. We then estimate the equation:

$$P_{jt} = \alpha_1 REG_{jt-1} + \beta X_{jt} + \varepsilon_{jt} \qquad (5)$$

where REG_{jt-1} measures the stringency of the regulation in country *j*, X_{jt} is a set of control variables that include, amongst others, a full set of country and year fixed effects, and ε_{jt}

is the error term. The equation is estimated with a fixed effects Poisson rather than negative binomial estimator since the bootstrapping of standard errors did not always succeed with the latter estimator.[14]

In order to explore how the effect of regulatory stringency varies according to the relative position of the recipient country vis-à-vis source countries, we define a dummy variable $FOLLOWER_{jt}$. The dummy is set to 1 if the recipient country's regulatory stringency is below the world's weighted average stringency. The weights represent the relative share of countries among all EST patents transferred globally in any one year such that the regulatory stringency of more important sources of non-resident patents counts more towards the global weighted average.[15] We then interact the $FOLLOWER_{jt}$ dummy with absolute stringency, which allows us to estimate the effect of raising regulatory stringency in countries that are lagging behind the world's weighted average, versus countries that are not. A similar set of control variables are used as in the dyadic analysis.

Results are shown in table 7. Columns (1) and (2) first report the estimation results for regulatory stringency without distinguishing between followers and leaders. Column (1) refers to a sample that includes all countries, whereas the sample of the estimation reported in column (2) includes only non-OECD countries. Consistent with our findings reported in the dyadic section 7.1, we find that absolute stringency does not have a statistically significant impact on total inward transfers for the full country sample. Similarly, in line with our results in section 7.2, absolute stringency increases patent inflows for the sample of non-OECD countries.

[14] Over-dispersion is far less pronounced at the monadic than at the dyadic level such that using the Poisson estimator is less problematic here. In any case, our results are robust toward using negative binomial without bootstrapped standard errors.

[15] We checked that our results hold with various definitions of the world average.

In column (3), we interact the FOLLOWER dummy variable with regulatory stringency. The coefficient for the regulatory stringency variable gives us the estimated semi-elasticity of regulatory stringency in countries that are at or above the world's weighted average stringency, i.e. where the FOLLOWER dummy variable is equal to 0. This coefficient is negative and statistically significant, implying that if the recipient country has an above average regulatory level, increasing this further by one unit reduces net patent inflows into the country by roughly 11 per cent. However, when the stringency in the recipient country is below average, then the estimated semi-elasticity is the sum of the regulatory stringency coefficient plus the coefficient of the interaction term. We find that tightening regulation by one unit increases net patent transfers by 8 per cent in laggard countries (-0.11 + 0.19 = .08). This is consistent with the result in column (2) that focuses on non-OECD countries, the majority of whom have below average regulatory levels, and explains the insignificant finding for regulatory stringency in column (1). That is, the negative effect of increasing regulatory stringency on transfers in leader countries cancels out the positive effect of increasing regulatory stringency on transfers in follower countries. Thus, explicitly focusing on total inward transfers rather than bilateral transfers, we confirm our previous finding that the effect of absolute regulatory stringency is conditioned by the recipient country's relative regulatory position.

7.4 Robustness tests

Results from a number of robustness tests for our dyadic framework estimations are reported in tables 8 and 9. In the interest of space, we only report estimates for equation (4) for the entire sample of countries, which includes our two main explanatory variables.[16]

7.4.1 Alternative estimators

An alternative approach for dealing with country-pair fixed effects is deployed in columns 1 and 2 of table 8. Blundell et al. (1999) argue that using a pre-sample mean scaling estimator is an attractive way of controlling for correlated unobserved heterogeneity when some of the explanatory variables are not strictly exogenous. We implement this method by including the pre-sample mean of the dependent variable, calculated over the period 1951 to 1991, as an additional explanatory variable. In column 1, we use a negative binomial estimation, while in column 2 a zero-inflated negative binomial estimation is used to account for the high proportion of zeros in our dataset.[17] The regulatory distance and the distance to export markets variables have a negative and statistically significant effect in both estimations. However, the coefficients are much larger than in the fixed effect estimations using the Hausman et al. (1984) approach, possibly because country-pair fixed effects may not be properly accounted for using the Blundell et al. (1999) approach.

In column 3 of table 8, we use OLS with a logged dependent variable.[18] The regulatory distance variables are robust to the change in estimator. However, using OLS, we now find that absolute regulatory stringency both domestically and in country *j*'s main export markets has a positive impact on transfers from country *i* to country *j*.

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[16] Robustness checks for equations 1, 2, and 3 are available from the authors upon request.

[17] We have 70 per cent of zeros in the full sample. This high proportion is not a problem when country-pair fixed effects are included since country pairs that experience zero transfer throughout the estimation period are dropped from the estimation.

[18] We use $\ln(1+P_{ijt})$ as the dependent variable to deal with cases when $P_{ijt}=0$.

Finally, column 4 accounts for possible dynamic effects by including the temporally lagged dependent variable. For this dynamic model, we apply the first-differenced GMM estimation method (Arellano and Bond 1991), since both fixed effects OLS and the conditional maximum likelihood estimators require strict exogeneity which is inconsistent with the presence of a lagged dependent variable. This model also allows us to account for the potential endogeneity of the regulatory variables. Lovely and Popp (2011) show that the availability of technology affects the willingness of policy makers to set environmental regulatory standards for SO_2 and NO_x emissions of coal-fired power plants. While their finding need not generalize to environmental product standards, such as the emission standards analysed in our study, the possibility of reverse causality cannot be excluded. We have no external variable which we could convincingly argue is a valid instrument within the present context. As an admittedly weaker alternative, the GMM estimator of Arellano and Bond (1991) allows us to use internal instruments, namely the regulation levels lagged by three or more periods which serve as instruments for the differenced potentially endogenous one period lags of regulation from the estimation model.[19] Using too many instruments can bias the GMM estimation results (Roodman 2009). The maximum lag of instruments is therefore restricted to two. Consistent estimation depends on the assumption of no serial correlation in the second-order differenced error term. This leads us to include two further temporal lags of the dependent variable after which this hypothesis can no longer be rejected (p-value 0.7576). Results from the first-differenced GMM estimator are consistent with our main negative binomial estimations.

[19] While all regulatory variables are presumed endogenous, the patent flows and stock variables are presumed pre-determined, leaving only the remaining variables as strictly exogenous.

7.4.2 Alternative dependent variables and other tests

In the first two columns of table 9, we use alternative dependent variables, restricting the sample to fuel injection technologies in column 1 and on-board diagnosis (OBD) technologies in column 2. Each of these groups of technologies represent about one third of the dataset. Again, our results for recipient regulatory distance are robust to changes in the dependent variable. Concerns about the potential endogeneity of $PAT_{-i,t-1}$ lead us to lag this variable by one additional year in column 3; results are robust. In column 4, we check whether our results are driven by the presence of the dominant sources and destinations of transfers, namely Japan, Germany and the US. Excluding these three countries from the estimations leads to the results reported in column 4, which are fully consistent with the main estimations, suggesting they are not driven by the presence of the dominant countries in the sample. In column 5, we address two further specification concerns. Our results could be spurious if our dependent variable were to simply capture general patent flows in all technologies rather than EST flows specifically. Our results on regulatory stringency and distance could also be spuriously driven by the fact that EU states move together in terms of regulatory level. We address these issues in column 5 by adding the total flow of patents from country *i* to country j in all technologies as an additional control variable and merging European countries into one single entity. The result on the regulatory distance beween source and recipient country is fully robust, while the coefficient on regulatory distance between the source and the recipient country's export markets retains its expected negative sign, but becomes statistically insignificant. Finally, applying alternative values of the discount rate used to calculate the patent stocks – specifically, 10 and 20 per cent – made no difference (robustness test results not shown).

8. Conclusion

In this paper we use data on automobile emission standards and non-resident patenting of associated compliance technologies in order to study the relationship between environmental regulation and the international transfer of ESTs. In line with several previous studies, we find evidence that higher absolute levels of regulatory stringency are associated with more inflows of ESTs, but crucially in our case, only for transfers from developed to developing countries.

In fact, more so than absolute regulatory stringency, our study shows that a consistently important predictor of inter-country transfers of ESTs is relative stringency. Across different country samples, model specifications and estimators, therefore, we find that countries are more likely to receive newly-innovated ESTs where their regulatory standards are closer to those in inventor countries. A possible explanation for the role of regulatory distance is that regulation-driven demand for ESTs is likely to be supplied by foreign innovators, as opposed to domestic innovation, where other countries have already recently innovated compliance technologies in response to similar standards.

Consistent with this interpretation we find that regulatory tightening in countries whose domestic standards are below the source-weighted world average raises total inflows of automotive ESTs. Conversely, regulatory tightening in recipient countries whose standards are already more stringent than the weighted world average leads them to receive fewer ESTs overall, possibly because demand for compliance technologies is supplied by domestic innovation. This distinction between leader and follower countries could explain our finding that absolute domestic regulatory stringency has a positive effect on transfers from developed countries into developing countries, but has no statistically significant effect in the full sample. Non-OECD countries invariably have lower environmental standards than innovating countries, such that regulatory tightening in the former is likely to reduce their regulatory distance to the latter, resulting in more inflows.

Another novel contribution is to demonstrate that inward technology transfer is also shaped by export markets. At least for the full sample of countries, ESTs are more likely to be transferred to recipient countries sending more of their automobile-related exports to markets whose environmental standards are closer to those in the original source countries of relevant technologies. A plausible explanation for this finding is that trade creates third-country induced demand for compliance technologies, with newly-innovated technologies "imported" into recipient countries in order to be "exported" in products for sale in foreign markets.

Our findings have a number of wider implications. One is that they suggest that the cross-border flow of newly-innovated ESTs needs to be understood as an inherently relational process. Attention therefore needs to be paid not only to absolute stringency in potential recipient countries, but also to the relative regulatory stringency between source and recipient countries. Likewise, it is important to consider the existence of third-country effects, and the possibility that trade creates additional demand in exporting countries for newly-innovated technologies. From a policy perspective, the results of the study suggest that accelerating the inward transfer of new ESTs can be achieved by regulatory tightening, but only in countries which are regulatory laggards. This would generally imply developing countries whose environmental regulatory stringency invariably lags behind the major source countries of ESTs which are developed economies.

Annex 1. Definition of IPC codes

Air-fuel ratios	
F01N3/05	Exhaust or silencing apparatus having means for purifying, rendering innocuous, or otherwise treating exhaust by means of air e.g. by mixing exhaust with air.
F02M67	Apparatus in which fuel-injection is effected by means of high-pressure gas, the gas carrying the fuel into working cylinders of the engine, e.g. air-injection type.
F02M23	Apparatus for adding secondary air to fuel-air mixture.
F02M25	Engine-pertinent apparatus for adding non-fuel substances or small quantities of secondary fuel to combustion-air, main fuel, or fuel-air mixture.
F02M3	Idling devices
Oxygen, NOX and temperature sensors	
F01N11	Monitoring or diagnostic devices for exhaust-gas treatment apparatus
F02D41/14	Electrical control of supply of combustible mixture or its constituents (introducing closed-loop corrections).
Fuel injection systems	
F02M39	Arrangements of fuel-injection apparatus with respect to engines; Pump drives adapted top such arrangements
F02M41	Fuel-injection apparatus with two or more injectors fed from a common pressure-source sequentially by means of a distributor
F02M43	Fuel-injection apparatus operating simultaneously on two or more fuels or on a liquid fuel and another liquid, e.g. the other liquid being an anti-knock additive
F02M45	Fuel-injection apparatus characterized by having a cyclic delivery of specific time/pressure or time/quantity relationship
F02M47	Fuel-injection apparatus operated cyclically with fuel-injection valves actuated by fluid pressure
F02M49	Fuel-injection apparatus in which injection pumps are driven, or injectors are actuated, by the pressure in engine working cylinders, or by impact of engine working piston
F02M51	Fuel injection apparatus characterized by being operated electrically.
F02M53	Fuel-injection apparatus characterized by having heating, cooling, or thermally- insulating means
F02M55	Fuel-injection apparatus characterized by their fuel conduits or their venting means
F02M57	Fuel injectors combined or associated with other devices
F02M59	Pumps specially adapted for fuel-injection and not provided for in groups F02M 39/00 to F02M 57/00
F02M61	Fuel injection not provided for in groups F02M 39/00 to F02M 57/00
F02M63	Other fuel-injection apparatus, parts, or accessories having pertinent characteristics not provided for
F02M69	Low-pressure fuel-injection apparatus
F02M71	Combinations of carburetors and low-pressure fuel-injection apparatus
Exhaust Gas Recirculation (EGR) valves	
F01N5	Exhaust or silencing apparatus combined or associated with devices profiting by exhaust energy

On-board diagnosis systems	
F02D41	Electrical control of combustion engines; Electrical control of supply of combustible mixture or its constituents
F02D43	Conjoint electrical control of two or more functions, e.g. ignition, fuel-air mixture, recirculation, supercharging, exhaust-gas treatment
F02D45	Electrical control not provided for in groups F02D 41/00 to F02D 43/00
F02M51	Fuel injection apparatus characterized by being operated electrically
F01N9	Electrical control of exhaust gas treating apparatus
Crankcase emissions and control	
F01M13/04	Crankcase ventilating or breathing: having means of purifying air before leaving crankcase, e.g. removing oil
Catalytic converters	
F01N3/08-34	Exhaust or silencing apparatus having means for purifying, rendering innocuous, or otherwise treating exhaust; for rendering innocuous by thermal or catalytic conversion of noxious components of exhaust
B01D53/92-96	Separation of gases or vapors; Recovering vapors of volatile solvents from gases; Chemical or biological purification of engine exhaust gases; Regeneration, reactivation or recycling of reactants.
B01J23/40-46	Catalysts comprising metals or metal oxides or hydroxides; of the platinum group metals

Annex 2. Country list

Argentina
Australia
Austria
Belgium
Brazil
Bulgaria
Canada
Chile
China
Cyprus
Czech Republic
Denmark
Egypt
Finland
France
Germany
Greece
Guatemala
Hong Kong
Hungary
Iceland
India
Indonesia
Ireland
Israel
Italy
Japan
Luxembourg
Mexico
Morocco
Netherlands
New Zealand
Norway
Panama
Philippines
Poland
Portugal
Romania
Russia
South Korea
Singapore
Slovakia
Spain
Sweden
Switzerland
Turkey
UK
USA
Ukraine

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Table 1. — Top 10 inventor countries (by patents filed) for automotive ESTs

Country	Number of inventions 1992-2007	Share of world total
Japan	64290	61.16%
Germany	15658	14.90%
USA	10166	9.67%
S Korea	4022	3.83%
France	2559	2.44%
UK	1513	1.44%
China	1296	1.23%
Russia	885	0.84%
Italy	710	0.68%
Sweden	646	0.62%

Source: Authors, based on data extracted from PATSTAT (2010)

Table 2. — Top 10 source countries of non-resident patent filings for automotive ESTs

Country	Number of patents transferred 1992-2007	Share of world total
Germany	147576	37.1%
Japan	103929	26.1%
USA	52949	13.3%
France	23164	5.8%
UK	15001	3.8%
Italy	14629	3.7%
Sweden	8402	2.1%
Austria	4708	1.2%
Switzerland	3583	0.9%
Canada	3167	0.8%

Source: Authors, based on data extracted from PATSTAT (2010)

Note: A single invention may be transferred to several countries through the patent system. Hence patent numbers in table 2 are higher than invention numbers in table 1.

Table 3. — Top 10 recipients of non-resident patent filings for automotive ESTs

Patent office	Number of patents 1992-2007	Share of world total
Germany	28884	7.3%
UK	21306	5.4%
France	20582	5.2%
Spain	18705	4.7%
Italy	18011	4.5%
Austria	17465	4.4%
USA	16730	4.2%
Sweden	16293	4.1%
Denmark	15515	3.9%
Switzerland	15316	3.8%

Source: Authors, based on data extracted from PATSTAT (2010)

Table 4. — Summary statistics

	mean	std. dev.	min.	max.	obs.
P_{ijt}	11.28	64.15	0.00	1203.00	35280
REG_{jt-1}	1.57	1.32	0.00	5.00	35280
$REGEXP_{jt-1}$	1.69	1.06	0.02	4.93	35280
$REGDIST_{ijt}$	1.00	0.99	0.00	5.00	35280
$REGEXPDIST_{ijt}$	0.92	0.77	0.00	4.93	35280
$ln(PAT_{i,t-1})$	2.01	2.04	0.00	8.53	35280
$ln(KPAT_{j,t-1})$	5.80	2.81	0.00	10.43	35280
$ln(PAT_{-i,t-1})$	4.35	2.74	0.00	8.65	35280
$IPR_{j,t-1}$	3.73	0.87	0.96	4.88	34560
$ln(GDP_{jt})$	25.79	1.57	22.60	30.05	35280
$ln(GDP\_percapita_{jt})$	9.00	1.27	5.79	10.91	35280

Notes: GDP and GDP per capita are in constant 2000 US dollars. GDP, GDP per capita and all patent variables (except the dependent variable) are logged to reduce the skewness in these variables.

Table 5 — Main estimation results

Model	**(1)**	**(2)**	**(3)**	**(4)**
REG_{jt-1}	0.0084 (0.0149)	0.0040 (0.0154)	-0.0274 (0.0187)	-0.0145 (0.0203)
$REGEXP_{jt-1}$		0.0364 (0.0358)		0.0112 (0.0404)
$REGDIST_{ijt-1}$			-0.0908*** (0.0137)	-0.0483** (0.0221)
$REGEXPDIST_{ijt-1}$				-0.0990*** (0.0284)
$PAT_{i,t-1}$	0.1783*** (0.0221)	0.1787*** (0.0221)	0.1776*** (0.0223)	0.1763*** (0.0223)
$KPAT_{j,t-1}$	0.3122*** (0.0560)	0.3162*** (0.0557)	0.3064*** (0.0559)	0.3098*** (0.0554)
$PAT_{-i,t-1}$	0.3869*** (0.0392)	0.3833*** (0.0391)	0.3856*** (0.0389)	0.3824*** (0.0389)
$IPR_{j,t}$	-0.0664 (0.0677)	-0.0639 (0.0681)	-0.0623 (0.0687)	-0.0554 (0.0694)
$lnGDP_{j,t}$	0.0055 (0.0320)	0.0054 (0.0321)	0.0054 (0.0315)	0.0051 (0.0320)
$lnGDPpercap_{j,t}$	0.2494*** (0.0526)	0.2441*** (0.0555)	0.2464*** (0.0522)	0.2409*** (0.0553)
Observations	20463	20463	20463	20463
Country-pairs	1389	1389	1389	1389

Note: *=significant at the 10% level, **=significant at the 5% level, ***=significant at the 1% level. The dependent variable is the number of patents transferred from country *i* to country *j* in year *t*. All models are estimated using a dyad fixed-effects negative binomial estimator and include a full set of year dummies (not reported for brevity). Bootstrapped standard errors in parentheses.

Table 6 — Estimation results for developed-developing country flows

Model	**(1)**	**(2)**
REG_{jt-1}	0.1710***	0.1086***
	(0.0313)	(0.0411)
$REGEXP_{jt-1}$	0.0551	0.1400
	(0.1318)	(0.1297)
$REGDIST_{ijt-1}$		-0.0850**
		(0.0350)
$REGEXPDIST_{ijt-1}$		0.1084
		(0.0788)
$PAT_{i,t-1}$	0.0461	0.0454
	(0.0556)	(0.0551)
$KPAT_{j,t-1}$	0.1048	0.1230
	(0.1046)	(0.1069)
$PAT_{-i,t-1}$	0.5525***	0.5417***
	(0.0782)	(0.0797)
$IPR_{j,t}$	-0.0736	-0.0766
	(0.1273)	(0.1310)
$lnGDP_{j,t}$	0.2205***	0.2189***
	(0.0575)	(0.0561)
$lnGDPpercap_{j,t}$	0.4789***	0.4817***
	(0.0817)	(0.0850)
Observations	3648	3648
Country-pairs	252	252

Note: *=significant at the 10% level, **=significant at the 5% level, ***=significant at the 1% level. The dependent variable is the number of patents transferred from country *i* to country *j* in year *t*. All models are estimated using a dyad fixed-effects negative binomial estimator and include a full set of year dummies (not reported for brevity). Bootstrapped standard errors in parentheses.

Table 7 — Total patent inflows

Model	**(1)**	**(2)**	**(3)**
REG_{jt-1}	0.0496	0.1863**	-0.1113**
	(0.0508)	(0.0731)	(0.0468)
$FOLLOWER_{jt-1}$			-0.5558***
			(0.1342)
$REG_{jt-1} * FOLLOWER_{jt-1}$			0.1944***
			(0.0359)
$lnPAT_{-j,t-1}$	0.0008***	-0.0065***	0.0006***
	(0.0003)	(0.0017)	(0.0002)
$lnKPAT_{j,t-1}$	0.5767***	0.5412***	0.5411***
	(0.0532)	(0.0857)	(0.0551)
$IPR_{j,t}$	0.2356	0.2341	0.1769
	(0.1572)	(0.4776)	(0.1571)
$lnGDP_{j,t}$	-5.1545***	-15.2557***	-5.3289***
	(1.2945)	(2.1320)	(1.3228)
$lnGDPpercap_{j,t}$	5.5478***	13.2922***	5.6384***
	(1.5086)	(2.1735)	(1.5252)
Observations	720	276	720
Countries	49	19	49

Note: *=significant at the 10% level, **=significant at the 5% level, ***=significant at the 1% level. The dependent variable is the number of patents transferred to country *j* in year *t*. All models are estimated using a fixed-effects Poisson estimator and include a full set of year dummies (not reported for brevity). Standard errors robust and clustered by country reported in brackets.

Table 8 — Robustness tests 1

Model	**(1)**	**(2)**	**(3)**	**(4)**
REG_{jt-1}	-0.0022	-0.0401	0.0224***	-0.0106
	(0.0367)	(0.0342)	(0.0086)	(0.0101)
$REGEXP_{jt-1}$	-0.0352	-0.0897	0.0332**	-0.0313
	(0.0613)	(0.0609)	(0.0148)	(0.0215)
$REGDIST_{ijt-1}$	-0.1075***	-0.1475***	-0.0897***	-0.0354***
	(0.0375)	(0.0369)	(0.0078)	(0.0129)
$REGEXPDIST_{ijt-1}$	-0.5737***	-0.5725***	-0.0312***	-0.129***
	(0.0504)	(0.0493)	(0.0093)	(0.0216)
lnP_{ijt-1}				0.444***
				(0.0164)
lnP_{ijt-2}				0.199***
				(0.0137)
lnP_{ijt-3}				0.124***
				(0.0147)
$lnPAT_{i,t-1}$	0.7338***	0.7352***	0.2166***	0.217***
	(0.0186)	(0.0187)	(0.0083)	(0.0147)
$lnKPAT_{j,t-1}$	0.3108***	0.0919	0.1252***	-0.0649***
	(0.0560)	(0.0592)	(0.0140)	(0.0131)
$lnPAT_{-i,t-1}$	0.4426***	0.4724***	0.0910***	0.0501***
	(0.0480)	(0.0485)	(0.0093)	(0.00913)
$IPR_{j,t}$	0.1068*	0.1307**	0.0617***	0.0873***
	(0.0563)	(0.0561)	(0.0213)	(0.0163)
$lnGDP_{j,t}$	-0.2978***	-0.2488***	-0.7678**	-0.475***
	(0.0204)	(0.0199)	(0.3019)	(0.174)
$lnGDPpercap_{j,t}$	-0.2832***	-0.2504***	0.8283***	0.662***
	(0.0373)	(0.0365)	(0.3166)	(0.181)
$lnMean(PAT_{i,pre-1992})$	0.3030***	0.3029***		
	(0.0229)	(0.0226)		
Dummy(Mean=0)	1.1436***	0.8856***		
	(0.0659)	(0.0673)		
Observations	34560	34560	20463	20463
Country-pairs	2352	2352	1389	1389

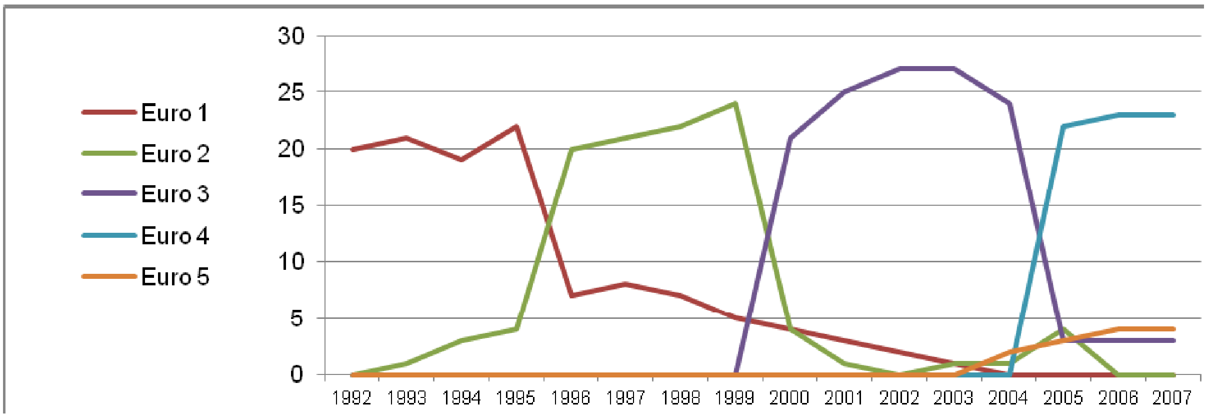
Note: *=significant at the 10% level, **=significant at the 5% level, ***=significant at the 1% level. The dependent variable is the number of patents transferred from country *i* to country *j* in year *t* (logged in columns 3 and 4). Columns 1 is estimated using negative binomial estimation. Column 2 is estimated using a zero-inflated negative binomial estimation. The inflation equation for the ZINB estimation includes $lnKPAT_{j,t-1}$, and the pre-sample mean. Columns 1 and 2 use the Blundell et al. (1999) approach for dealing with fixed effects. Column 3 is estimated by OLS with dyad fixed effects, column 4 by first-differenced GMM. Standard errors robust and clustered by country-pair in parentheses. All models include a full set of year dummies (not reported for brevity).

Table 9 — Robustness tests 2

Model	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
REG_{jt-1}	0.0165	-0.0099	-0.0027	0.0178	0.0203
	(0.0247)	(0.0374)	(0.0215)	-0.0243	(0.0335)
$REGEXP_{jt-1}$	0.0859	0.0381	0.0770*	0.0662	-0.0282
	(0.0754)	(0.0690)	(0.0413)	-0.0426	(0.0621)
$REGDIST_{ijt-1}$	-0.0564*	-0.0901**	-0.0585***	-0.0407**	-0.0584**
	(0.0317)	(0.0435)	(0.0196)	-0.0205	(0.0285)
$REGEXPDIST_{ijt-1}$	-0.1267***	-0.1340**	-0.0893***	-0.1281***	-0.0477
	(0.0445)	(0.0561)	(0.0257)	-0.03	(0.0350)
$lnPAT_{i,t-1}$	0.3469***	0.1782***	0.1653***	0.6558***	0.0077
	(0.0239)	(0.0244)	(0.0218)	-0.0209	(0.0368)
$lnKPAT_{j,t-1}$	0.4058***	0.4732***	0.7979***	0.2134***	-0.0808
	(0.0709)	(0.0572)	(0.0335)	-0.0421	(0.0508)
$lnPAT_{-i,t-1}$	0.2732***	0.1798***		0.5087***	0.1416***
	(0.0551)	(0.0438)		-0.0298	(0.0291)
$lnPAT_{-i,t-2}$			-0.0482**		
			(0.0199)		
$lnPATA_{i,t}$					0.6237***
					(0.0364)
$IPR_{j,t}$	0.0602	0.0311	-0.0581	-0.1009	0.3902**
	(0.1019)	(0.0918)	(0.0675)	-0.0656	(0.1605)
$lnGDP_{j,t}$	-0.0611	0.0054	-0.0338	0.0732	-0.4069***
	(0.0451)	(0.0404)	(0.0298)	-0.0468	(0.0915)
$lnGDPpercap_{j,t}$	0.2063***	0.1362**	0.1748***	0.4474***	-0.0193
	(0.0606)	(0.0574)	(0.0539)	-0.0599	(0.0651)
Observations	13785	13599	20463	16785	7542
Country-pairs	934	921	1389	1141	518

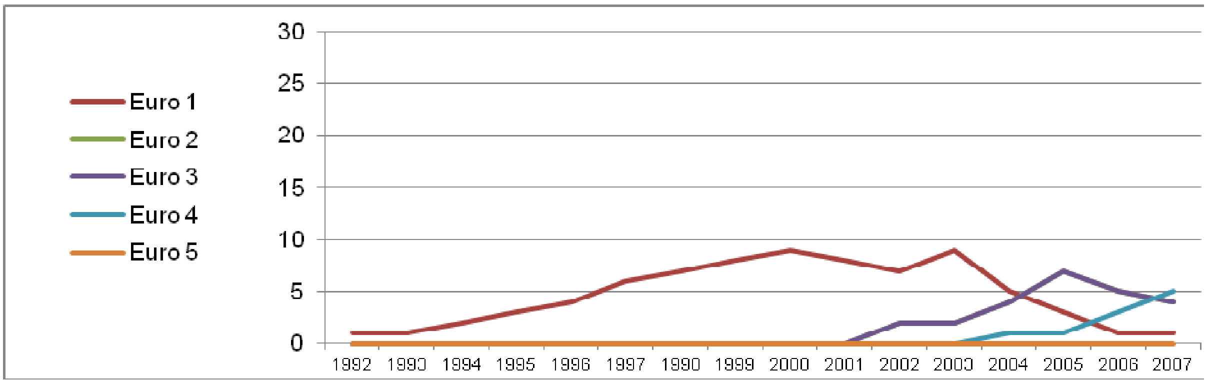
Note: *=significant at the 10% level, **=significant at the 5% level, ***=significant at the 1% level. The dependent variable is the number of patents transferred from country *i* to country *j* in year *t*. All models are estimated using a dyad fixed effects negative binomial estimator with bootstrapped standard errors in parentheses. Columns 1 and 2 restrict the sample to patents related to fuel injection technologies and on-board diagnosis systems, respectively. Column 4 drops Germany, Japan and USA from the sample. In column 5, EU15 countries are considered as a single entity. All models include a full set of year dummies (not reported for brevity).

Figure 1 – Number of adopters of Euro-equivalent standards in OECD countries 1992-2007



Source: Authors, based on data in Perkins and Neumayer (2012)

Figure 2 – Number of adopters of Euro-equivalent standards in non-OECD countries 1992-2007



Source: Authors, based on data in Perkins and Neumayer (2012)

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