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Environmental Innovation of Transportation Sector in OECD Countries

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Climate change is a global concern and transport sector contributes to it significantly. This study aims to identify the factors which contribute to the development of environmental innovation in transport sector and to examine their effects. The analysis is carried out via a panel regression model with a dataset for 23 OECD countries for the period between 1997-2012. Environmental patent data in transportation is used as a proxy for the innovation capacity. The independent variables consist of value added, environmental stringency, CO2 emissions and GDP growth. Empirical exercises suggest that innovation in transport has a positive relationship with CO2 emissions and a negative relationship with environmental stringency. The negative impact of environmental regulation on innovation in transport sector is an important insight. This can be associated with excessive adjustment costs of regulation with respect to benefits of improved efficiency by innovation. Furthermore, innovation may be realized in response to rising fuel prices rather than in response to environmental mitigation policies. The positive effect of CO2 emissions may imply that as the CO2 emission caused by transport sector rises, innovation capacity increases through the search for more energy-efficient vehicles. This study contributes to the literature by analyzing the utilization of technology for environment specifically in the field of transport. The analysis can be conducted in a more comprehensive manner including manufacturing sector. The results might provide some important insights for policy makers as well as executives in transportation sector.

Keywords: environmental innovation; environmental stringency; technology ; transport

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1 Introduction

Concerns on climate change have caused the adoption of United Nations Framework Convention on Climate Change (UNFCC) in 1992 to avoid damage caused by human activity on the climate system (UNFCC, 1992). With Paris Agreement, countries have become dependent on long term climate change goals of keeping the rise in global temperature under 2 ^{0}C above pre-industrial levels and further restricting global warming under 1.5 ^{0}C above pre-industrial levels to the end of the century (United Nations, 2016).

Transport sector plays an important role in the economies as it serves as an enabler for international trade by transportation of goods and as a global connector by passenger transportation. In terms of climate change, transport is one of the most important sectors as a source of greenhouse gas emissions. In a report by IEA (2009, p.3), it is stated that 25% of energy-related CO2 emissions are produced by transport sector which holds crucial importance in climate change mitigation. Moreover, technological transition is designated as a requirement for sustainability in companion with policies adopted to utilize these technologies in the report. In this context, transport sector experience diligent attention to achieve such goals due to its fuel dependency and CO2 emission reduction potential (Rogelj et al. 2015). Technological development and related applications is regarded as an area to mitigate climate change on a large scale (Sims et.al.,2014, p.613). The prominence of transport sector for stringent climate change mitigation is also stressed by Zhang et al. (2018), indicating that technological transformation in the sector offers the most remarkable capacity to lower CO2 emissions.

Climate change mitigation in transportation is an area which attract great attention by policymakers, international organizations, governments and researchers. Jolley (2004) asserts that transportation demand rises at a faster pace than income growth in developing countries. Moreover, it is pointed out that technology holds significant potential to compensate the mismatch between exponential increase in transportation demand and relatively fixed environmental capacity in the long run.

This study aims to detect the determinants of climate change mitigation technology development in transport sector and to scrutinize their impacts. The rest of the paper proceeds as follows. In part 2, literature on the relationship between innovation and environmental regulation is discussed and then studies investigating the role of transport sector in climate change mitigation are reported. In part 3, the determinants of innovation in transport sector to mitigate climate change are identified in line with the existing studies and empirical analysis is conducted. Afterwards, the results are discussed in section 4. The last part includes concluding remarks on the contribution of the study and recommendations for upcoming research.

2 Literature Review

Research on the determinants of environmental innovation in specific to transport sector lacks in the literature to the best of our knowledge. So, the literature review starts with presentation of empirical studies which explore the relationship between environmental regulation and technology development. Subsequently, studies on climate change mitigation in the transport sector are outlined.

The role of technology in environmental protection is underlined by Porter and Van Der Linde (1995). They argue that environmentalism and industrial competitiveness are not necessarily opposites, asserting that it can enhance competitiveness with higher productivity. Jaffe and Palmer (1997) find that environmental compliance costs have a positive effect on R&D expenditures, however they find no significant evidence for the relationship between environmental costs and patents for a panel of US manufacturing industries by using Pollution Abatement Control Expenditures (PACE) data as a proxy for stringency of environmental policy. Lanjouw and Mody (1996) show the correlation between environmental regulation and innovation by analyzing patent data and PACE data for the US, Germany and Japan for the period between 1972-1986. They employ all R&D and patent data without eliminating groups which are irrelevant to environment. In order to deduct better insights, they suggest to study chosen industries in focus with disaggregated data. Moreover, Brunnermeier and Cohen (2003) utilize panel data for 146 US manufacturing industries for the span between 1983-1992 to identify determinants of environmental innovation. They report that PACE is positively associated with environmental innovation. Popp (2006) analyzes air pollution control patent data for US, Japan and Germany between 1970-2000. Analysis reveals that environmental regulation has a direct impact on domestic emission control innovation. From a different perspective, Jaffe et al. (2003) draw attention to link between technological development and environmental policy within the context of environmental economics.

Another line of research gathers on connection between transport, urbanization and climate change mitigation. Economic growth and transport are intertwined and mobilization of products in large distances along with decentralization because of rapid urbanization has increased transport demand further (Kejun, 2010). Dulal et al. (2011) advocate high-density settlement and high-density employment to mitigate climate change. Emission reduction alternatives are examined via scenario analysis in terms of cost and scope for urban transportation in developing countries (Wright and Fulton, 2005). A set of measures with an emphasis on modal shift is proposed as the possible minimum cost policy after comparing fuel technology and policies for modal shift.

Technological innovation is not the solution to reduce emissions from transport merely, but behavioral change to promote modal shift to more environmentally friendly modes and policies to control demand for mobility are other areas to tackle as discussed in IEA (2015) and EEA (2012). In terms of policy development, Colvile et al. (2001) suggest that as technology and transport system gradually become capable of stable decrease of emissions from road transport, policies on air quality will become more rigid. This argument implies a long run cointegration between technology and climate change mitigation. In the same manner, Howey et al. (2010) assess climate change mitigation stringent goals of UK and conclude that dramatic changes which dictate innovative technologies coupled with long run coherent policies are required for UK in fulfilling the CO2 reduction commitment. Likewise, an important mitigation tool for climate change caused by transport sector is stated as advances in vehicle technology in Shaheen and Lipman (2007). These improvements consist of increased utilization of electric vehicles and utilization of alternative energy sources accompanied with the necessary technology to use them. By the same token, Chapman (2007) asserts that improvements in transport technology is essential to address climate change issue in the long run. On the other hand, it is also claimed that policy to promote behavioral change holds critical role in the short run to benefit from the technological developments in a solid way. Jolley (2004) supports this view by stating that emissions caused by transportation can be reduced with a sustainable transportation strategy integrated with developments in transport technologies. Van Der Zwaan et al. (2013) conduct a scenario analysis for the period until 2100 to examine technology diffusions to fulfill a predetermined climate change policy. It is predicated that the dominating vehicle technology along with alternatives can be identified by R&D practices of private sector. As implied by this finding, transformation pathway can be designated by innovation. In a recent empirical work by Beltrán-Esteve and Picazo-Tadeo (2015), environmental performance in the transport sector is studied for 38 countries between 1995-2009. The results show that environmental performance improvement is primarily driven by eco-innovations.

3 Data and Methodology

In the scope of this study, factors which determine environmentally related innovation in transport sector are identified to analyze their relationship with innovative output across time and countries. The analysis is conducted with a panel data covering the period between 1997-2012 with annual frequency for 23 OECD countries. The countries are Australia, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States. Innovative capacity of transport sector in relation to environment has been measured by patents as a dependent variable following Costantini et al. (2017) and Dechezleprêtre et al. (2013). Besides, to capture differences across countries, patent data based on inventor's residence is considered. The number of granted patents at the European Patent Office (EPO) for climate change mitigation technologies related to transportation are retrieved from OECD (2018a).

Explanatory variables set consists of a diverse group of parameters. Firstly, following Jaffe and Palmer (2007), value added is taken as an explanatory variable. In order to take the size of the sector into account, data for share of value added by the transport sector is obtained from OECD (2018b). Environmental regulation is also considered as a determinant in environmental innovation in transport. For this variable, Environmental Policy Stringency Index is taken from OECD (2018c). The index measures the degree of penalty for actions causing pollution or environmental damage within a range between 0 and 6, the former implying zero stringency and the latter referring to highest level. Bearing in mind that transport is one of the primary contributors to emissions as discussed earlier, CO_2 emissions from transport sector in relation to GDP data acquired from OECD (2018d) is also included as an independent variable. From a macroeconomic point of view, the integration of transport sector and economic growth suggests the inclusion of a variable about demand. Thus, GDP growth series are taken from OECD (2018e) as it is referred to as one of the determinants of transport demand in Zhang et al. (2018). Descriptive statistics for the panel dataset is presented in Table 1.

Table 1: Descriptive Statistics of Variables

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Patents	368	50	102	0	499
Value Added	368	5	1	3	9
Environmental Stringency	368	2	1	0	4
CO2 Emissions	368	85	42	24	250
GDP Growth	368	2	3	-9	11

The modeling procedure is to be discussed after a brief description of panel data and explanation on panel regression. To begin with, panel data can be defined as observations for the same subjects (firms, countries etc.) at multiple points in time. Panel data is a rich source to analyze as it has two dimensions: cross-sectional units and time. It enables to explain heterogeneity across subjects and dynamic effects that are not obvious in cross sections (Greene, 2010).

In panel estimation, two methods can be utilized: fixed effect and random effect. The fixed effect model controls for unobserved data or omitted variables due to unavailability of data. On the other hand, random effect model assumes all relevant variables are included.

By the structure of our dataset for 23 countries and 16 time periods, a panel regression model of the following form is to be estimated;

$$PAT_{it} = \beta_0 + \beta_1 VALUE_{it} + \beta_2 STR_{it} + \beta_3 CO2 + \beta_4 GROWTH_{it} + u_{it} \tag{1}$$

where

$$u_{it} = \mu_i + v_{it}$$

In (1), PAT is patents, β_0 is intercept term, VALUE is value added, STR is environmental stringency index, GROWTH stands for GDP growth and CO2 refers to CO2 emissions. In these kind of models, year dummies can be used to control for year specific effects in the data. In that case, the model to be estimated is as follows;

$$PAT_{it} = \beta_0 + \beta_1 VALUE_{it} + \beta_2 STR_{it} + \beta_3 CO2 + \beta_4 GROWTH_{it} + \beta_5 YD_{it} + u_{it} \quad (2)$$

where

$$u_{it} = \mu_i + v_{it}$$

In (2), YD stands for year dummies. In these models, μ_i are assumed to absorb individual specific effects (Baltagi, 2008, p.14). These two model types will be compared based on Akaike Information Criterion (AIC). AIC developed by Akaike (1973) is a technique to compare different model specifications. In statistical modeling, two common considerations about the predictive capacity are over-fitting and under-fitting. An over-fitted model includes unnecessary variables which inflate the variation. An under-fitted model lacks relevant information by omitting related variables, in which case the model fails to capture the true relationship. AIC is based on the view that a model should seize the real relationship between variables without including irrelevant parameters. AIC is calculated by the following equation for each model i:

$AIC_i = -2MLL_i + 2k_i$ where MLL stands for the maximum log likelihood value and k is the number of estimated parameters.

4 Empirical Findings

Panel modeling is not a straightforward process as the properties of cross-sectional data impose some restrictions. So, we adopt a stepwise approach. Initially, the evaluation of random effect or fixed effect model specification is carried out by Hausman test (Greene, 2010, p.420). This analysis has led to fixed effect modeling. Afterwards, assessment of model specification (1) and (2) reveals that year dummy variables improve AIC in the estimation. The estimation results are presented in Table 2. According to the results, all variables except for value added are significant determinants of innovation capacity building in transport sector. Besides coefficient of determination also known as R2 of 19.28 % indicate that the model can explain almost 20% of the deviation in innovation of transport sector. Moreover, the F-statistic of 4.1 with p-value of 0.00 reveals that the model is significant.

Diagnostic tests for the base model including cross-sectional dependence test developed by Pesaran (2004), modified Wald test for groupwise heteroscedasticity in (Greene, 2010) and Wooldridge autocorrelation test (Wooldridge, 2002) are shown in Table 3. All explanatory variables along with time dummies are included for preliminary analysis with only exception for autocorrelation test as test specification does not allow for time dummies. According to diagnostic test statistics, there is cross-sectional dependence, heteroscedasticity and autocorrelation problems in the model. In this case, main assumptions of Ordinary Least Squares (OLS) estimators are violated and model is not reliable.

Table 2: Base Model Estimation Results

Variables	Coefficient	P-value	Year Dummies	Coefficient	P-value
VALUE	3.28	0.30	1998	4.20	0.54
STR	-8.68**	0.02	1999	11.23*	0.10
CO2	0.19**	0.04	2000	13.40*	0.05
GROWTH	0.78**	0.02	2001	15.74**	0.02
INTERCEPT	0.94	0.96	2002	19.82**	0.01
			2003	30.13***	0.00
			2004	32.79***	0.00
			2005	41.54***	0.00
			2006	49.63***	0.00
			2007	55.41***	0.00
			2008	49.79***	0.00
			2009	54.80***	0.00
			2010	54.30***	0.00
			2011	53.08***	0.00
			2012	37.91***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

Table 3: Diagnostic Tests for the Base Model

Test	Statistics	P-value
Wooldridge Test	50.98***	0.00
Modified Wald Test	5„375.97***	0.00
Pesaran's CD Test	13.80***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

In order to handle the aforementioned problems, Driscoll and Kraay regression is employed as it gives heteroscedasticity consistent standard errors and provides robustness to general forms of cross-sectional and temporal dependence (Hoechle, 2007). The results of estimations are displayed in Table 4.

Table 4: Regression Results with Driscoll-Kraay Standard Errors

Model 1			Model 2		
Variables	Coef.	P-value	Variables	Coef.	P-value
VALUE	3.28	0.31	VALUE	-	-
STR	-8.68 *	0.05	STR	-8.94 **	0.03
CO2	0.19 *	0.06	CO2	0.22 *	0.06
GROWTH	0.78	0.45	GROWTH	-	-
INTERCEPT	0.94	0.97	INTERCEPT	19.16	0.16
YD			YD		
1998	0.62 ***	0.00	1998	3.83 ***	0.00
1999	0.63 ***	0.00	1999	11.22 ***	0.00
2000	1.39 ***	0.00	2000	13.42 ***	0.00
2001	1.60 ***	0.00	2001	14.46 ***	0.00
2002	1.99 ***	0.00	2002	18.20 ***	0.00
2003	3.18 ***	0.00	2003	28.92 ***	0.00
2004	3.73 ***	0.00	2004	32.94 ***	0.00
2005	5.24 ***	0.00	2005	41.38 ***	0.00
2006	6.10 ***	0.00	2006	49.98 ***	0.00
2007	5.95 ***	0.00	2007	55.98 ***	0.00
2008	7.81 ***	0.00	2008	48.10 ***	0.00
2009	10.99 ***	0.00	2009	49.24 ***	0.00
2010	8.21 ***	0.00	2010	53.72 ***	0.00
2011	9.05 ***	0.00	2011	51.69 ***	0.00
2012	9.41 ***	0.00	2012	35.33 ***	0.00
R2	19%		R2	19%	
F-test (19,15)	23.92 ***	0.00	F-test (17,15)	23.46 ***	0.00

Notes: *, ** and *** indicate 10%, 5% and 1% levels of significance respectively.

In Table 4, Model 1 is estimated with all independent variables along with time dummies and Model 2 is estimated by eliminating insignificant variables to obtain a parsimonious model. The F-test results of both models indicate overall significance of the variables in explaining innovation in transport. As shown in Table 4, all the year dummies are significant. This result is reasonable as the technology development along with environmental regulations entail a long period of time. Besides, there is a lag between a technological change and its adaptation. Environmental stringency is a significant factor and has a negative effect on environmental innovation in transportation. This inverse relationship can be explained by an implied and indirect negative impact of environmental policies on firms in reference to the lack of consensus on the directional impact of environmental regulation as stated by Leiter et al. (2011). Companies operating in transport sector may anticipate that cost of adjustment to environmental regulations outweighs the efficiency gains of technology development. Moreover, as innovation process does not give results in short term, firms may be in expectation of looser environmental regulation in the future thereby they don't undertake capital and organizational responsibility by investing in research and development. In addition, innovation might be driven by efforts to remedy dependence of transport sector on petroleum, likely in response to volatility in energy prices which is another implication for focus of transport companies on costs. The positive sign of CO2 emissions might indicate that search for energy-efficient vehicles results in increased technology development when emissions of the sector rise. This plausible insight might indicate that transport sector embraces environmental mitigation after it is realized that the damage is continuous.

5 Conclusion

The role of technology development draws close attention to mitigate environmental damage. As an important source of air pollution (Colvile et al., 2001), innovation of transportation sector is important to control climate change. The objective of this study is to identify the determinants of such innovative capacity and analyze their effects. To do this, a panel regression for environmental patents in transport sector is performed on input variables of environmental stringency, CO2 emissions by transportation, GDP growth and share of value added by the sector for the period between 1997-2012 for 23 OECD countries. The empirical findings suggest that environmental stringency and sectoral CO2 emissions are significant factors determining innovative capacity in transportation. The stringency of environmental regulation has negative correlation with innovation in transportation. This might be due to costs being firms' primary focus rather than environmental mitigation and energy prices acting as a primary catalyst in technology development for transportation. The positive effect of CO2 emissions on innovation suggest that efforts for higher energy efficiency in transport sector end up with innovation as CO2 emissions rise. This study is limited to the analysis of transport sector only, however manufacturing sector can be also considered due to the interaction between one another. Besides the availability of data limits the time span in the analysis, thus time horizon can be extended by utilizing different parameters to proxy environmental stringency.

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