

Examining the differences in the impact of climate change on innovation between developed and developing countries: Evidence from a panel System GMM analysis

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Abstract

This article aims to explore the dynamic relationship between innovation and climate changes for a sample of 60 countries. We performed an aggregated analysis in which we use the whole sample (60 countries) and a disaggregated analysis in which we split the sample in developed (36 countries) and developing (24 countries). We estimate a balance panel dynamic System Generalized Method of Moment approach for the period 2008-2014. Findings of the aggregated analysis indicate that for the whole sample, there is a positive response from climate change to innovation. Recent climate changes have a positive impact on the innovation process. The disaggregate analysis shows that for developed countries, there is a positive response from climate changes to innovation only for total CO₂ emission and CO₂ emission from natural gas. However, there is a negative response from the others CO₂ emission toward innovation. For the developing countries, the overall results indicate that there is no significant effect from climate change to innovation. Furthermore, findings indicate also, that the level of growth and research and development expenditure exert a positive effect on innovation process for both aggregate and disaggregate analysis.

Keywords: climate change; CO₂ emission; patents; innovation; developed and developing countries; SGMM

JEL codes:Q56, Q58, O34, O44

1. Introduction

The international scientific and policy community has agreed in recent times that the climate is indeed changing with rapid rates and the negative consequences are not a future concern but a consideration for the present already. The most recent evidence for the consensus was demonstrated in the signing of the Paris Agreement by the United Nations Framework Convention for Climate Change (UNFCCC) in 2015 (UNFCCC, 2015). The Conference of Parties (COP) agreed there that it is imperative for the survival of the planet to limit the global temperature to 2 degrees by 2020. The Intergovernmental Panel on Climate Change (IPCC) stresses that in order to do so a rapid decarbonization of the global economy is necessary: IPCC (2014) estimates that in order to stabilize carbon emissions (not even to reduce) by 2050, almost 60% of carbon intensity of global Gross Domestic Product (GDP) is required¹. At the same time, the United Nations Sustainable Development Goals (SDGs) emphasize the need for climate action (SDG 13), access to clean water and energy for all (SDG 6 and 7) with the underlying factor for all SDGs being a livable planet, where the nature is protected to provide a sustainable home for future generations.

To achieve these set targets, a drastic change in the consumption and generation of energy is at least required, in combination with serious commitment by policy makers to prioritize the reduction of greenhouse gas emissions. To do so, substantial investments will be needed in innovation activities; with the IPCC stressing that possibly the decisive catalyst to change the current trajectory is the investments in Research and Development (R&D) activities as they are also related to the costs of policies. (Dechezlepretre et al, 2016a). Linnenluecke et al. (2019) explain that it is due to the urgency of the need for a systematic transition, studies such as Tan (2010) have analysed how international, regional and national systems of innovation need to adapt to foster the rapid development of clean technologies. Examples are the natural gas innovations in the UK and Netherlands to substitute coal consumption (Verbong and Geels, 2007) or the most popular *Energiewende* in Germany (Hake et al, 2015).

IEA (2008) explains that due to the diversity and variety of energy systems, natural resources, national policies and contexts, the solution to promoting climate change innovation will have to be holistic and across the border of the innovation- invention spectrum: from the idea creation until the commercialization of the technologies and its potential for diffusion to multiple environments and countries. In the 2019 meeting of the IEA's *Technology and Collaboration Programme*, the IEA's Executive Director Dr Birol said "A more integrated and holistic approach to energy technology innovation is required to reach a sustainable energy future, which means more partnerships among those in the room" talking to leading energy specialists in Paris in June 2019 (IEA, 2019).

As per Su and Moaniba (2017), climate-change related technologies, measured in the number of patents, developed have been on a constant increase after the oil crises of the 1970s. The questions, however, are now whether their potential has been fully exploited within a policy and industrial framework, and whether their costs have been restricted for developing countries that suffer from low economic growth and lack of access to financial sources.

Thus far, the literature examining the effect that innovation has on climate change and particularly greenhouse gas emissions is not limited in numbers. A number of studies promoted the idea of sustainable economic growth, or in other words, economic growth that does not

¹ With an assumption that the global economy will growth by 2.5% annually on average.

damage the environment, and by extension, technological progress and innovation that is environmental friendly (Nino, 2016; Grimsley, 2016). Studies have also demonstrated that the substitutability of innovation on clean versus dirty activities seems to be perfect and that with appropriate environmental policies, clean innovation can be promoted without any long-run losses of economic growth (Aghion and Howitt, 2008; Acemoglu et al., 2012).

More recent studies take a step back and try to identify what are the drivers for the development of clean technologies in an effort to propose more appropriate policies. Grubb (2004), among others, aimed at identifying catalysts promoting clean innovations, stressing that climate change “cannot be solved with a single “silver bullet” but rather through various portfolio options from different sectors” (Su and Moaniba, 2017). Veugelers (2012) compared these determinants/promoters of environmental friendly technologies in various sectors in the US economy. Interestingly enough, he found that in some sectors regulation and taxes were the most enhancing factors while in others, voluntary agreements drove the clean innovations development.

Su and Moaniba (2017) were the first ones to convert the literature’s findings in a more concrete question of whether there exists an impact of the changes in emissions on the development of environmental –related technologies. In other words, they did not focus on the most common view of “Innovation \rightarrow Climate change / GHG emissions” but on the reverse “Climate change / GHG emissions \rightarrow Innovation”. Using the number of patents as a proxy for innovation, they concluded that carbon dioxide emissions levels from gas and liquid fuels affect positively innovations while the opposite effect was found for the carbon dioxide emission levels from coal consumption.

To better understand the dynamic relationship between innovation and climate changes, we used a sample of 60 countries. Taking into several specificities for these two groups of countries and in order to get full benefits from results comparison, we performed an aggregated analysis in which we use the whole sample (60 countries) and a disaggregated analysis in which we split the sample in developed (36 countries) and developing (24 countries). We estimate a panel dynamic System Generalized Method of Moment (SGMM) approach for the period 2008-2014.

Empirical results indicate that the effect of climate changes on the innovation process differs from one group of countries to another. As for example, we found that for developed countries, there is a positive response from climate changes to innovation only for total CO₂ emission and CO₂ emission from liquid fuel. However, for the others greenhouse gas emissions there are negative impacts toward innovation. For the developing countries, the overall results indicate that there is no significant effect from climate change to innovation.

This paper contributes to the existing literature since it aims to estimate and compare the impact of CO₂ emissions on innovations among country group of different developmental stages. This research question is in the core of the environmental-innovation literature and is based on the argument that innovative activities are responsive to climate change trends, specifically air pollution. As discussed above, the study complements that straight forward argument that innovation and technology has the potential to improve climatic conditions by examining the opposite direction of the relationship. Also, this study expands on the study by Su and Moaniba (2017) where they implicitly stressed that their limitation is the absence of inference to different country groups. Our study makes the argument that the development of innovation behaves dissimilarly among different groups of countries, and as such, policies cannot be globally homogeneous. To do so, a panel dynamic System Generalized Method of Moment (SGMM)

approach is used for the period 2008 to 2014 for a sample of 60 countries (36 developed and 24 developing ones).

The rest of this paper is structured as following. Literature review is given in section 2. The methodology of this paper is given in section 3. The empirical analysis is discussed in section 4. Section 5 concludes and addresses some policy recommendations.

2. Theoretical framework

During the last years an import part of literature has been considerably interested on the innovation-environment quality relationship (Huaman and Tian, 2014; Lee and Min, 2015). The development of the carbon capture and storage (CCS) technology is considered as a vital component that decreases carbon emissions (Huaman and Tian, 2014). Using data related to Japanese manufacturing firms over the period 2000–2010, Lee and Min (2015) found that the green R & D for ecoinnovation could decrease carbon emissions and increase firm value.

In the same line of idea, Zhang et al. (2017) checked if environmental innovation facilitates carbon emissions reduction. They used a panel data of China's 30 provinces during 2000–2013, and the performed the system generalized method of moments (SGMM *henceforth*) as econometric approach. Findings indicate that most proxies used to measure environmental innovation reduce carbon emissions.

The study of Elliott and Pye (1998) propose that strategies and policies that promote technology innovation are considered as driver for greater industrial energy efficiency. They reported that the implementation of these policies and strategies leads to a reduction of carbon emissions and industrial energy consumption by 12.1% and 12.4%, respectively. However, without changing economic growth, these reductions will increase to 35.65% and 33.1% in 2030. Similarly, Smithers and Blay-Palmer (2000) have confirmed the crucial role of the adoption of technology and planning to manage climatic challenges.

In a recent study, Lin and Zhu (2019) analyzed the effect of renewable energy technological innovation on climate change in china over the period of 2000-2015. Empirical findings support that renewable energy technological innovation (RETI *henceforth*) exerts a significant effect of the CO₂ emissions. Since the impact of RETI on CO₂ emissions could be different, the authors conduct a nonlinear analysis to define the optimal threshold. They found that the effect of RETI on the CO₂ emissions decreases with the rising of coal-dominated energy consumption structure. However, this effect increases with the growing proportion of renewable energy generation.

The theoretical background of this study is based on the “*Sustainable – Innovative Growth*” (SIG) model as proposed by Su and Moaniba (2017). In that framework, they combined key determinants to sustainable innovative growth, such as economic growth, innovation and climate change. Links and connections demonstrate that environmental considerations are included in every aspect of the growth process. Within the SIG framework, this study aims at investigating the relationship between innovation and climate change by controlling for the Research and Development (R&D) expenditures, population dynamics and income level of each country.

Innovation is traditionally captured in the quantitative side of the literature by a patent indicator, for example patents count (Su and Moaniba, 2017) or patents applications or patents grants (Sinha, 2008; Josheski and Koteski, 2011; Dosi et al., 2015). Our study uses another patent indicator: patents in force as captured by WIPO. This was done to capture quantitatively the idea that a simple innovation without ensuring that it is adopted by the society cannot make a difference (as in Popp, 2003) and hence, the model will be based on commercialized or “in force” patents. Unfortunately, this indicator is not reported in a disaggregated manner as per the nature of the patent.

3. Methodology

In this section, we initially describe the sample and the empirical approach used in this study. Second, we analyze the descriptive statistics and the correlation matrix.

3.1 The sample

This study focuses on the innovation-climate change relationship for a sample of developed and developing countries. Initially, the sample was made by 114 countries. However, due to the availability and the continuity of country’s level informations, several countries have been excluded. As for example, we excluded countries for which data on patents were missing or with informations not available for at least five years. Hence, only 85 countries have been retained. Moreover, we eliminated 25 countries for which data on all indicators of CO2 emission and others greenhouse gas emissions were missing. The final sample was then reduced to only 60 countries.

In order to better understand the dynamic relationship between innovation and climate changes, the whole sample was divided into two sub-samples. The first one covers 36 developed and the second one is related to 24 developing countries. These countries are listed in appendix A1. This study covers the period of 2008 to 2014. We have limited this study only to this period since we are constrained by the availability of data related to patents and climate change (CO2 emissions).

In this study, patents were used as a proxy for innovation. Contrary to previous studies that used patents count (Su and Moaniba, 2017) or patents applications or patents grants (Sinha, 2008; Josheski and Koteski, 2011; Dosi et al., 2015), we used in this study patents in force as proxy for innovation. Data on patents in force were collected from the World Intellectual Property Organization (WIPO *henceforth*). Data for this variable are available from 2008 to 2017². As discussed in the Theoretical framework, we have used patents in force as measure of innovation.

Following Su and Moaniba (2017), we used five indicators of climate change. As for example, we used the total carbon dioxide emission (CO2 emission), others greenhouse gas emissions like CO2 emissions from electricity (CO2EL), CO2 emissions from gaseous fuel (CO2GF), CO2 emissions from liquid fuel (CO2LF) and CO2 emissions from solid fuel (CO2SF). All these five indicators and others macro data were collected from the World Development Indicators database (WDI). However, data related to climate change are limited only to 2014.

² For more details, see this patents statistical profile at this link
https://www.wipo.int/ipstats/en/statistics/country_profile/profile.jsp?code=NL

The use of carbon dioxide emission and others greenhouse gas emissions as proxy of climate change was motivated by the lack of single index that quantify climate change and its effects.

3.2 Econometric approach, model specification and variables definition

To explore the dynamic relationship between innovation and climate change in 60 developed and developing countries, we performed an empirical strategy that is based on two steps. In the first one, we present and discuss results of an aggregated analysis in which we use the whole sample (60 countries). In the second and the third steps, we conduct a disaggregated analysis in which we split the sample in developed (36 countries) and developing countries (24 countries).

As econometric approach, we performed the SGMM method following Zhang et al. (2017). Within a small number of periods (7 years) and a relatively large number of individual (60 countries) with reference to the number of years, the dynamic panel data are considered the appropriate method. Furthermore, compared to the Difference Generalized Method of Moments (DGMM *henceforth*), the SGMM provides robust results. It leads to efficient and consistent parameter estimates. Moreover, using this method, the problem of endogeneity and heterogeneity are solved. Within ordinary least squares (OLS *henceforth*), pooled and fixed effect method, estimations are faced to the problems of omitted variable bias and measurement error (Zhou et al., 2013; Teixeira and Queirós, 2016).

To test the validity of instrument, the Hansen test of Hansen (1982) or the Sargan test of Sargan (1958) are usually used. However, within small sample; the Sargan test is more suitable (Iqbal and Daly, 2014). As our sample is made only by 60 countries divided into 36 developed and 24 developing countries, we performed the Sargan test to check the over-identifying restrictions. Furthermore, the SGMM method requires no significant autocorrelation of second-order (AR2) in the residual series. It is for this reason that we used the Arellano-Bond test for the first-order autocorrelation (AR1) and the Arellano-Bond (1991) test for the second-order autocorrelation AR(2).

Based on the superiority of SGMM in solving several regression problems compared to others method, we performed this method as econometric approach. Also, we conduct the Sargan and the Arellano-Bond tests as diagnostic tests to check for the validity of instrument and for the absence of second-order autocorrelation. To test the dynamic innovation-climate changes relationship using the SGMM method, we write the following model in the equation (1):

$$PAT_{i,t} = \beta_0 + \beta_1 PAT_{i,(t-1)} + \beta_2 CLICH_{i,t} + \beta_3 GDPPCG_{i,t} + \beta_4 RD_{i,t} + \beta_5 POPG_{i,t} + \varepsilon_{i,t}$$

Where:

PAT is the dependent variable measured by The Napierian logarithm number of patents in forces by year. $PAT_{i,(t-1)}$ is the lagged variable of the dependent variable. $CLCH_{i,t}$ is the main independent variable that represents climate changes and measured by five indicators: total carbon dioxide emission (CO2 emission), others greenhouse gas emissions like CO2 emissions from electricity (CO2EL), CO2 emissions from gaseous fuel (CO2GF), CO2 emissions from liquid fuel (CO2LF) and CO2 emissions from solid fuel (CO2SF). To do this, five models are conducted separately. In each model, we use an indicator of climate changes as independent variable.

To assess the dynamic relationship between climate change and innovation, besides climate changes as main independent variables, we introduce others variables that can affect directly or indirectly the number of patents. As for example, we include in the econometric model the level of growth measured by the annual percentage growth rate of GDP per capita (*GDPPCG*). Countries with a sufficient level of growth promote the research and development activities by providing necessary budget and necessary databases, software, skills, international cooperation that are able to increase the probability of patenting (Inglesi-Lotz, et al, 2018). We also introduce a variable related to the expenditure on R&D (*RD*). This variable was measured by research and development expenditure (% of GDP). Since the works of Griliches (1984), Bound *et al.* (1984) and later Peeters and Van Pottelsberghe (2006), Bongor and Bansal (2007) and more recently Inglesi-Lotz et al. (2018), R&D expenditure was considered as a driver factor for invention, innovation and patenting. Finally, to control the quantity effect of each country, we include a variable that reflects the population growth which is measured by the annual growth of population. We think that the size population can affect the climate changes-innovation relationship. The employed variables definition used in this study are summarized in Table 1.

Table 1. Variables definition

Variable	Definition	Source
Pat	The Napierian logarithm number of patents in forces by year	WIPO (2008-2014)
GDPPCG	GDP per capita growth (annual %)	WDI(2008-2014)
RD	Research and development expenditure (% of GDP)	WDI(2008-2014)
POPG	Population growth (annual %)	WDI(2008-2014)
CO2	CO2 emissions (metric tons per capita)	WDI(2008-2014)
CO2EL	CO2 emissions from electricity and heat production, total (% of total)	WDI(2008-2014)
CO2GA	CO2 emissions from gaseous fuel consumption (% of total)	WDI(2008-2014)
CO2LF	CO2 emissions from liquid fuel consumption (% of total)	WDI(2008-2014)
CO2SF	CO2 emissions from solid fuel consumption (% of total)	WDI (2008-2014)

3.3 Descriptive analysis and correlation

Table 2 below summarizes descriptive statistics of all variables used in this study during the period 2008-2014. To make comparison, statistics displayed in this table will be analyzed within two groups: developed and developing countries. For each variable, we analyze the mean, the standard deviation, the maximum and the minimum values.

Table 2. Descriptive statistics

<i>Developing countries</i>						<i>Developed countries</i>				
Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
Pat	153	8.417	2.044	4.625	13.995	239	10.521	2.166	4.407	14.743
co2	168	3.654	3.071	0.086	15.646	252	8.407	3.997	3.376	22.385
co2el	168	38.284	19.565	0.000	72.667	246	42.673	16.051	0.472	80.751
co2ga	168	23.103	22.403	0.000	84.897	231	24.439	10.891	3.852	49.753
co2lf	168	39.941	24.228	7.270	93.996	245	48.635	17.800	4.189	93.829
co2sf	168	28.846	25.733	0.000	78.146	245	25.180	19.650	0.000	89.555
Rd	125	0.594	0.451	0.016	2.021	238	1.782	0.974	0.329	4.348
Gdppcg	168	2.582	3.871	-14.421	10.103	252	0.197	3.483	-14.560	13.216
Popg	168	1.004	1.448	-1.666	5.367	251	0.551	0.901	-2.258	5.322

Table 1 indicates that the average number of patent (PAT) is 8.417 equivalent to for the developing countries and 10.521 for developed countries. Since the numbers of patents are in logarithm, the equivalent average values are 4523 and 37086 patents respectively for developed and developed countries. From these statistics, we notice the superiority of developed countries in term of the yearly number of patents. The maximum value of patent also confirms this superiority. We found that developed countries register a maximum value of 14.743 (equivalent to 2 528154 patents) compared to 13.995 (equivalent to 1 196 606 patents) for developing countries.

With regard to climate change³proxied par CO2 emission and others greenhouse gas emissions, statistics indicate that developed countries emit more CO2 and greenhouse gas than developing countries. Most of developed countries are industrialized countries which used in most local and foreign investment energy that are in most of case non-clean energy. From table 1, we notice that the average value of total CO2 emission is 3.654 metric tons per capita for developing countries and 8.407 metric tons per capita for developed countries. The same observation was detected for CO2 emissions from electricity consumption, CO2 emissions from gaseous fuel consumption and CO2 emissions from liquid fuel consumption. However, we found that developing countries are more emitter of CO2 emissions from solid fuel consumption (% of total) compared to developed countries. The average values of CO2SF are 28.846% and 25.180% respectively for developing and developed countries.

Research and development expenditure in % of GDP (RD) registered on average a value of 0.594% for developing countries. However, for developed countries the mean value of R&D in % of GDP is 1.782%. From these statistics, we can conclude that developed countries are more oriented toward promoting R&D. developed countries grant more attention to improve the quality and quantity of researches and patenting in order to grow output.

The most surprising, that for the selected sample, descriptive statistics indicates that developing countries recorded a higher level of growth compared to developed countries. We found that over the period 2008-2014, the average value of GDP per capita is 2.582% for developing countries against 0.197% for developed countries. The weak level of growth recorded by developed countries can be explained by the negative effect of the international financial growth of 2008 when the world economy is slowing down.

To control the effect of the population size in the innovation-climate change relation, we have added the variable of growth population. We think that the size of population can affect both CO2 emission and the number of patents. From table 2, we notice that the average rate of the population growth in developing countries is 1.004% against 0.551% in developed countries.

Table 3 gives the level of correlation between all variables used in this study. The most important that independent must be not correlated.

³ For more detail on the evolution of climate change (CO2 emission) in developed and developing countries, see appendix A2.

Table 3. Correlation Matrix

	Pat	co2	co2el	co2ga	co2lf	co2sf	Rd	gdppcg	popg
Pat	1.0000								
co2	0.4181	1.0000							
co2el	0.0758	0.3491	1.0000						
co2ga	0.0376	0.0267	-0.0792	1.0000					
co2lf	-0.2100	-0.1878	-0.4821	-0.3881	1.0000				
co2sf	0.2317	0.2756	0.6069	-0.3375	-0.7131	1.0000			
Rd	0.4149	0.4414	0.0715	-0.0644	0.0302	0.0719	1.0000		
Gdppcg	-0.0640	-0.1480	0.0020	0.0658	-0.2373	0.1318	-0.1333	1.0000	
Popg	-0.1223	-0.0226	-0.1872	-0.1601	0.3885	-0.3220	0.0137	-0.0155	1.0000

From table 3, we notice that the level of correlation between variables is very weak. The only exception is for the association between CO2SF and CO2EL with a level of 60.69%. It is worth to inform that these two variables are dependent variables and they are tested separately in our econometric models. Hence, we confirm the absence of multicollinearity.

4. Discussion of empirical findings

In this section we discuss results of the aggregated analysis in which we use the whole sample (60 countries) and a disaggregated analysis in which we split the sample in developed (36 countries) and developing countries (24 countries).

4.1 The aggregated analysis

Table 4 presents the results of the five models (depending on the CO2 indicator used) for the full sample. For the five models, the lag of patents (PAT) is positively related to the dependent variable and statistically significant at 1%. This means that the current number of patents is positively dependent to the numbers of the previous year.

With regard to the effect of the CO2 emission on innovation, three out of five models show that there is a positive and statistically significant response from emissions (climate change) to innovations (patents). Results indicate that total CO2 emission, Carbon dioxide emission from electricity and from solid fuel consumption increase the number of patents. A high proportion of innovation can be explained by the change in such types of emissions. This finding indicates that for the whole sample, the propensity to innovate as response to climate change is mainly influenced by the total CO2 emission, the CO2EL and the CO2SF. Also, the positive coefficients indicate strong innovation responses to such types of emissions –due to the perceived importance that is given globally to these sources of emissions and their negative consequences, and due to their higher concentration levels and increasing trends for all countries, compared to the other sources of CO2 emissions. The positive coefficients confirm a priori expectations from the theoretical framework and confirm the results of Su and Moaniba (2017).

However, we found that emissions from liquid fuel (CO2LF) have a negative impact on patents. The highest is the carbon emission from liquid fuel consumptions has the lowest influence on the patent development. This means that development of innovation does not respond positively to the increase in carbon dioxide emissions from liquid fuel consumptions. The negative coefficient of CO2LF also confirms the results of Su and Moaniba (2017: 59) that find a

negative impact of CO2 emissions from liquid fuels to the number of patents. With regard to the effect of emissions from gas it was found to not exert any significant influence to the number of patents.

Results displayed in Table 4 indicate that for the whole sample, there is a positive and significant relationship between R&D expenditure in % of GDP and the dependent variable (PAT) for all the five models. An increase in the percentage allocated to research and development increases the possibility of patenting. Research and development is considered as a key factor to stimulate firm invention and innovation. This positive association is similar to the finding Griliches (1984) and Bound et al. (1984) who found strong evidence between R&D spending and the number of patents. Similarly, Hall et al. (1986) and Hall et al. (2005) also have reported a positive association between R&D and patents. This finding corroborate the results of Peeters and Van Pottelsberghe (2006), Bonger and Bansal (2007) and more recently Inglesi-Lotz et al. (2018).

The level of growth is positively and significantly correlated with the dependent variable only for the two first models, however no significant effect for the rest of models. Countries with high level of growth have the potential to get the possibility of patenting. Registering a satisfactory level of growth, countries will invest in research and development to improve the quality of education, to get patents in order to grow out-put. This result is similar to the work of Inglesi-Lotz et al. (2018).

Table 4. Results of SGMM for the whole sample

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Pat	CO2	CO2EL	CO2GA	CO2LF	CO2SF
patL1.	0.675	0.692	0.627	0.363	0.533
	33.490***	28.930***	24.730***	18.610***	15.340***
Co2emission	5.170	1.968	0.140	-1.962	1.672
	3.910***	5.770***	0.540	-3.940***	3.920***
Rd	3.260	4.309	4.914	5.044	5.689
	3.860***	4.710***	4.660***	8.060***	8.680***
Gdppcg	0.525	0.747	0.717	0.081	0.402
	2.280**	3.150***	3.630	0.260	1.340
Popg	-4.882	-1.096	-4.176	-4.585	-6.746
	-1.130	-0.270	-1.030	-1.050	-1.720
_cons	2.576	1.756	3.233	6.291	3.350
	4.030***	4.580***	8.330***	8.520***	8.150***
AR(1)	-2.071	-2.106	-2.050	-1.952	-2.061
	(0.038)	(0.035)	(0.040)	(0.050)	(0.039)
AR(2)	1.720	1.723	1.655	1.398	1.585
	(0.085)	(0.084)	(0.097)	(0.162)	(0.113)
Sargan	26.197	22.772	29.421	22.140	20.274
	(0.124)	(0.247)	(0.089)	(0.277)	(0.378)
Obs.	282	282	282	282	282

4.2 *The disaggregated analysis*

Table 5 presents the results of the estimation when only developed countries were chosen as a country group. Two out of five models show that there is a positive response from emissions (climate change) to innovations (patents): CO2 total and CO2 from Gas (CO2GA). Compared to the whole sample, the response of innovation to climate change is less announced than for the whole sample. There is a positive response only from CO2 total and CO2 from Gas. Hence, we can conclude that for the developed countries, the possibility to innovate and patent a climate-change technology is more influenced only by CO2 total and CO2 from Gas. Also, findings indicate that there is strong innovation response to such types of carbon emissions. The positive coefficient here indicates that the innovation activities of the developed economies respond to the total changes in CO2 emissions and CO2 from Gas. Countries have made international commitments to reduce their total level of emissions and hence, they respond to overall emission changes with development of technologies.

For the other three models, results show negative and statistically significant coefficients. An increase of CO2 emissions from electricity, liquid and solid fuel consumption decreases significantly the number of patents. This means that in the developed countries there is a weak innovation response to the increases in carbon emissions from electricity, liquid and solid fuel consumptions. Based on these results, governments of developed countries should grant more importance on the research and development of technologies that aimed to reduce the total CO2 emission and more precisely the CO2 emission from Gas.

As discussed for the whole sample, we found that the lag of patents, the R&D in % of GDP and the GDPPC are positively correlated with the dependent variable. An increase in the R&D increases the number of patents in developing countries.

In contrary to the findings for the whole sample, the population growth exerts a positive and significant effect on the innovation level. Researches output is seemed to be increased in countries with high population. Reciprocally, the number of patents maybe increased also. As for example, in countries with high population like China and India, the average number of publication over the period 1996-2013 is 93349 and 401435 respectively (Inglesi-Lotz et al. (2018)). However, in countries with weak population, the level of research output is also very weak. As for example, the average number of publication in Iceland and Luxemburg is only 359 and 246 respectively (Inglesi-Lotz et al. (2018)). These statistics support a strong relationship between the size of population, the level of research output and probably the number of patents.

Table 5. Results of SGMM for developed countries

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Pat	CO2	CO2EL	CO2GA	CO2LF	CO2SF
patL1.	0.804	0.826	0.611	0.656	0.810
	59.170***	97.680***	13.860***	54.860***	68.100***
co2	0.087	-0.027	0.012	-0.017	-0.007
	9.230***	-14.950***	13.450***	-11.950***	-5.730***
Rd	0.445	0.219	0.177	0.619	0.536
	9.770***	5.240***	9.080***	16.340***	15.160***
Gdppcg	0.002	-0.001	0.007	0.002	0.007
	1.360	-0.070	9.350***	1.670*	10.510***
Popg	-0.005	-0.045	0.033	0.092	0.061
	-0.300	-3.790***	2.460***	3.620***	2.780***
_cons	0.649	2.690	3.610	3.381	1.258
	5.270***	20.700***	11.360***	21.040***	16.460***
AR(1)	-1.671	-1.698	-1.282	-1.585	-1.616
	(0.094)	(0.089)	(0.199)	(0.112)	(0.106)
AR(2)	1.066	0.986	0.376	0.832	0.920
	(0.286)	(0.324)	(0.706)	(0.405)	(0.357)
Sargan	20.282	29.967	25.367	26.240	24.266
	(0.346)	(0.052)	(0.148)	(0.123)	(0.186)
Obs.	191	187	175	185	185

For the developing countries, results in Table 6 indicate that there is no significant response from climate change to innovation, with the exception of total CO2 that present a positive and statistically significant coefficient. This means that there is no significant response of innovation to the other types of CO2 emissions. Developing countries' policymakers and innovators also react and intensify their innovative efforts taking the aggregate CO2 emissions as a signal for climate change trends. The second remark from results displayed in table 6 is that the coefficient of total CO2 emission for the developing countries is higher than this for the developed countries. This implies that for developing countries, the number of patent is more sensitive to the dynamic of climate changes rather than in developed countries.

As discussed for the whole sample, we found that the lag of patents, the R&D in % of GDP and the GDPPC are positively correlated with the dependent variable. An increase in these variables increases the number of patents in developing countries. In contrary to the findings for the whole sample and developed countries, the population growth does not exert any significant effect.

Table 6.Results of SGMM for developing countries

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Pat	CO2	CO2EL	CO2GA	CO2LF	CO2SF
patL1.	0.275	0.195	0.365	0.224	0.222
	12.210***	4.930***	10.200***	9.360***	5.180***
co2	2.318	-0.145	1.555	-0.917	-0.867
	6.150***	-0.160	1.240	-0.860	-1.510
Rd	2.644	3.673	3.625	2.517	3.500
	10.310***	15.050***	15.510***	14.660***	17.230***
Gdppcg	-0.025	1.452	0.894	0.753	0.989
	-0.050	2.470***	2.820***	1.280	1.220
Popg	1.874	1.350	-1.220	0.452	0.223
	0.700	0.510	-0.640	0.160	0.280
_cons	3.970	4.826	3.314	5.263	4.751
	12.770***	5.250***	7.590***	11.470***	7.820***
AR(1)	-1.389	-1.465	-1.329	-1.445	-1.624
	(0.164)	(0.142)	(0.183)	(0.148)	(0.104)
AR(2)	1.490	1.641	1.493	1.590	1.133
	(0.136)	(0.101)	(0.135)	(0.111)	(0.156)
Sargan	11.309	12.431	8.980	12.674	11.872
	(0.913)	(0.866)	(0.973)	(0.854)	(0.891)
Obs.	92	92	92	92	92

5. Conclusion and policy recommendations

This study's main purpose is to extend the theoretical notion proposed by Su and Moaniba (2017) that innovation reacts to changes in climate trends (measured in carbon dioxide emissions). Su and Moaniba (2017) explicitly say that their results are to be interpreted globally and not to make cross-country comparisons. Hence, the contribution of this study is to investigate whether there are differences in the quantitative way that innovation absorbs changes in emissions between developed and developing countries.

When looking at the overall group of 60 countries, the results confirm those of Su and Moaniba (2017). The countries propensity to produce patents is impacted by the levels of carbon dioxide emissions. Carbon dioxide emissions from gas and solid fuel consumptions have significant positive impacts on patenting activity while negative significant impact from of carbon emissions from liquid fuel consumption on the number of patents.

The empirical results indicate also that the effect of climate changes on the innovation process differs from one group of countries to another. As for example, we found that for developed countries, there is a positive response from climate changes to innovation only for total CO2 emission and CO2 emission from liquid fuel. However, for the others greenhouse gas emissions there are negative impacts toward innovation. For the developing countries, the overall results indicate that there is no significant effect from climate change to innovation except from total CO2 emissions.

Negative or statistically insignificant coefficients imply weak innovation responses to changes in climate. Since the indicator for innovation is total patenting activity in force, negative or statistically insignificant coefficients might also imply that the specific types of emissions are not considered important by innovators or innovation policy makers. Additionally, the observation of the emission trends of the specific pollutants might not encourage innovation as the transition to low-carbon economy gives a signal that such emissions, for example the liquid fuel (petrol) related, will decrease systemically and no more innovation is required.

The overall lack of impact from climate changes to innovation for developing countries can be explained in a variety of ways. Firstly, developing countries emit much lower levels of carbon dioxide emissions than developed and hence, the impact of emissions through air pollution is not tangible or a priority for policy makers that have to deal with other issues such as low-income levels and poor living conditions. Secondly, innovation in developing economies does not boom due to lack of human and capital infrastructure as well as lack of access to financial means and funding. Hence, in many cases, the adoption of new technologies is highly dependent on the trading spillovers from developed countries. That fact is also one of the possible limitations of our study and a point for future research: to examine the technological spillovers between developed and developing countries vis-à-vis their climate change related innovative capacity.

The policy implication derived from this study's findings is that interventions from government or funding institutions to show commitment and facilitate R&D are needed to produce technologies towards reducing emissions from coal and natural gas. Policymakers in developed and developing countries should react to the innovation-climate change process through the possible linkage found in this paper. As for example, developed countries are invited to facilitate R&D towards reducing emissions from total CO₂ and from Gas. While developing countries should grant more importance to channel R&D towards reducing total CO₂ emissions.

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Appendix A1. Sample of Developed and Developing Countries

Developed countries				Developing countries			
1	Australia	19	Italy	1	Armenia	13	Jordan
2	Austria	20	Japan	2	Bosnia and Herzegovina	14	Kazakhstan
3	Belgium	21	Latvia	3	Brazil	15	Madagascar
4	Canada	22	Lithuania	4	Bulgaria	16	Mexico
5	Chile	23	Luxembourg	5	China	17	Peru
6	Croatia	24	Malta	6	Colombia	18	Romania
7	Cyprus	25	Netherlands	7	Costa Rica	19	Serbia
8	Czech Republic	26	New Zealand	8	Egypt	20	Turkey
9	Denmark	27	Norway	9	Georgia	21	Ukraine
10	Estonia	28	Poland	10	Guatemala	22	Uzbekistan
11	Finland	29	Portugal	11	Hungary	23	Vietnam
12	France	30	Singapore	12	India	24	Zambia
13	Germany	31	Slovak Republic				
14	Greece	32	Spain				
15	Hungary	33	Sweden				
16	Iceland	34	Switzerland				
17	Ireland	35	United Kingdom				
18	Israel	36	United States				

Appendix A2. Trends in climate change

Average annual evolution of CO₂ emission in some selected developed and developing countries

Years	<i>Developed countries</i>					<i>Developing countries</i>				
	CO ₂	CO ₂ EL	CO ₂ GA	CO ₂ LF	CO ₂ SF	CO ₂	CO ₂ EL	CO ₂ GA	CO ₂ LF	CO ₂ SF
2008	9.06	42.08	21.84	50.18	24.48	3.71	38.57	23.48	40.94	27.77
2009	8.55	41.79	21.88	51.49	23.65	3.46	39.64	22.86	41.38	27.58
2010	8.83	41.86	23.26	49.81	24.02	3.63	39.69	23.19	40.55	27.94
2011	8.41	42.03	22.71	49.59	24.62	3.80	39.85	23.06	39.74	29.47
2012	8.13	42.35	22.82	49.35	24.99	3.72	40.27	23.01	39.28	29.68
2013	8.09	41.27	22.62	49.41	25.00	3.66	40.34	22.88	38.83	29.80
2014	7.79	40.22	21.70	50.58	24.61	3.60	41.28	23.24	38.86	29.69

All data used in this table are in % except of CO₂ which is in metric tons per capita. Data are collected from the World Development Indicators Database. For more details on definition of CO₂, CO₂EL, CO₂GA, CO₂LF and CO₂SF, see Table 2 relative to variables definition.