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Emissions distribution in post – Kyoto international negotiations: a policy perspective

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Abstract
An abundant scientific literature about climate change economics points out that the future participation of developing countries in international environmental policies will depend on their amount of pay offs inside and outside specific agreements. These studies are aimed at analyzing coalitions stability typically through a game theoretical approach. Though these contributions represent a corner stone in the research field investigating future plausible international coalitions and the reasons behind the difficulties incurred over time to implement emissions stabilizing actions, they cannot disentangle satisfactorily the role that equality play in inducing poor regions to tackle global warming.

If we focus on the Stern Review findings stressing that climate change will generate heavy damages and policy actions will be costly in a finite time horizon, we understand why there is a great incentive to "free ride" in order to exploit benefits from emissions reduction efforts of others. The reluctance of poor countries in joining international agreements is mainly supported by historical responsibility of rich regions in generating atmospheric carbon concentration, whereas rich countries claim that emissions stabilizing policies will be effective only when developing countries will join them.

Scholars recently outline that a perceived fairness in the distribution of emissions would facilitate a wide spread participation in international agreements. In this paper we overview the literature about distributional aspects of emissions by focusing on those contributions investigating past trends of emissions distribution through empirical data and future trajectories through simulations obtained by integrated assessment models. We will explain methodologies used to elaborate data and the link between "real data" and those coming from simulations. Results from this strand of research will be interpreted in order to discuss future negotiations for post Kyoto agreements that will be the focus of the next Conference of the Parties in Copenhagen at the end of 2009.

A particular attention will be devoted to the role that technological change will play in affecting the distribution of emissions over time and to how spillovers and experience diffusion could influence equality issues and future outcomes of policy negotiations.

Key words: climate change, equality, emissions, technology, spillovers

JEL classification: Q52, Q53.

1. Introduction

The Conference of Parties in Copenhagen at the end of 2009 represents a crucial step for future negotiations about emissions stabilizing policies. The world is facing one of the biggest challenges to development that has never experienced in the past: the strong environmental and socioeconomic problems deriving from global warming caused by economic activity. A wide majority of scientists and policy makers agree on the fact that if appropriate policies will not be implemented within a reasonable lapse of time, the human kind could experience disasters that will strongly affect standards of life of future generations. If we consider the Brundtland's Report definition (WCED, 1987; p. 43) of sustainability according to which sustainable development is intended as a form of development that satisfies "the needs of the present generation without compromising the ability of future generations to meet their own needs" we can understand why weak and fragmented actions against global warming can lead to undesirable growth paths.

Within this perspective the priority is to set up the most effective policies to curb the increasing trend of emissions over time that until now does not appear to stabilize yet. A strand of literature in environmental economics refers to the well known Environmental Kuznets Curve (EKC) hypothesis. The prior idea behind this concept (Grossman and Krueger 1991) is that if we are able to identify a bell shaped relationship between the level of income and pollution and a turning point beyond which the level of emissions begins to decrease the best way to deal with environmental problems is to foster growth. Though some EKC evidence has been found for many pollutants, evidence is very weak for pollutants generating climate change. One of the main reasons would mainly lie in the public good nature of clean air. In other words, all countries face an incentive to "free ride" by enjoying positive externalities deriving from emissions reduction policies without bearing the relative costs (Ansuategi and Escapa, 2002). The main finding of the EKC in a context of increasing emissions is that growth is not the best tool to deal with global warming, but appropriate policies are needed to reach a turning point in the relationship between income and emissions.

As mentioned by the scientific literature (Cantore and Canavari, in press), the main problem concerning climate change policies is that to reduce effectively the level of emissions a very strong condition is needed: the involvement and a high reduction burden for developing countries. This finding seems to meet the main concern raised by the past Bush American administration claiming that a USA participation in climate change international policies would depend on a strong commitment of emerging areas in meeting pollution mitigation constraints. The involvement of Annex B[1] countries in emissions stabilizing policies that created the conditions for the signature of the well known Kyoto Protocol was frustrated by the refusal of the main polluter country, namely USA, to ratify the agreement. The stop to a full implementation of the Kyoto agreement generated many doubts on its effectiveness to tackle global warming in the short run and uncertainty in the negotiations to set up post Kyoto international emissions constraint agreements.

The argument provided by the past USA administration to refuse the commitment to climate policies does not take into account the main argument provided by the poorest regions: the involvement of developing countries in emissions stabilizing policies could strongly reduce their growth rates and welfare levels (Cantore and Canavari, in press). In other words it is very unlikely that emerging countries will be able to reduce greenhouse gas emissions by bearing reasonable welfare costs. This situation mainly creates two problems. From one side, as outlined by the game theoretical literature, if countries take policy choices on the basis of the pay off generated by a

[1] The Kyoto Protocol designs as Annex B countries those which committed themselves as a group to reduce their emissions of greenhouse gases. Annex B includes developed countries and those in transition to market economies.

specific strategy it is very unlikely that stable world coalitions aimed at reducing emissions can arise (Altamirano Cabrera *et al*., 2008), though a wider participation could be favoured by specific money transfers from rich countries to poorest regions in order to create incentives to join the club of pollution stabilizing countries (Carraro *et al*., 2006). From the other side even if developing countries should gain or pay a low cost from an emissions reduction commitment an equity issue arises. Developing countries could not be still available to join emissions stabilizing policies for many reasons:

- In an intertemporal perspective poorest regions could not be available to pay now for mitigation policies in order to enjoy benefits in the future. The climate change economics literature widely stresses that it exists a mismatch between the timing of paying for policies and that for enjoying environmental benefits (Tol *et al*., 2004). Electoral and political conditions often impose short term policy views and the time horizon of the climate change problem is well beyond that of many governments settled around the world. An important issue of intergenerational equity arises over time.

- In a cross country perspective developing countries could perceive their mitigation costs too high or their benefit too low in relation to those paid by richer countries, by raising an issue of intragenerational equity.

- In a multidimensional perspective emerging areas could refuse to join international agreements because they feel that they were not historically responsible in generating global warming or they could not perceive to be vulnerable to climate change. In other words other variables such as the geographical distribution of emissions and climate change damages are relevant in climate change negotiations to set up emissions stabilizing policies.

Previous climate change economics literature mainly focussed on the role of welfare costs and benefits to influence climate change negotiations. Our opinion is that researchers should also consider how they are distributed among countries according to equity principles and other relevant variables that may affect policy considerations. This paper mainly focuses on the distribution of emissions as important factor to investigate with the aim to extract useful insights for the understanding of global warming political negotiations.

From a policy perspective and for future environmental negotiations two elements are crucial: the perception of developing countries of past responsibility of rich countries and the perception of rich countries towards future responsibility of developing countries in generating atmospheric carbon concentration. As outlined by Duro and Padilla: (2008; p. 456) "The inequality in per capita CO_2 emissions between countries shows different responsibilities in the generation of greenhouse gases and the contribution to climate change. Therefore, the analysis of this inequality sheds light on the debate about the different control and mitigation measures to be applied in different regions. In fact, distribution problems have become the most important issue to deal with in global climate change policy negotiations and agreements. Taking distribution problems properly into account in policy design leads to an increase in the perceived fairness of the measures and facilitates widespread participation".

The present paper presents the literature about the path of the inequality in the distribution of emissions in the past arising from the empirical evidence (Section 2), the literature about the future distribution of emissions from integrated assessment model (Section 3) and the role that technological change and the transfer of technology will play in affecting the distribution of emissions and consequently, political negotiations of emissions stabilizing policies (Section 4). Section 5 will conclude.

2. Empirical evidence about the distribution of emissions

There are several studies that have applied distributive analysis tools to the analysis of climate change. Alcántara and Duro (2004) and Sun (2002) analyzed the inequality in energy intensity across OECD countries, which, according to their results, experienced a strong decrease in the period 1971–1998. Sun (2002) used mean deviation as a dispersion measure and also analyzed the differences between certain subgroups of countries. Alcántara and Duro (2004) employed the Theil index to measure these inequalities. This index allowed them to weight observations according to their GDP and to apply a consistent decomposition of inequality by subgroups. Hedenus and Azar (2005) employed the Atkinson inequality index to analyze the inequality for different natural resources, including carbon emissions per capita. According to their results, the Atkinson index showed a decrease in the inequality in emissions per capita over time. Heil and Wodon (1997) used the Gini index to analyze the inequality of emission across countries. They decomposed the Gini index to analyze the contribution of two income groups (poor and rich countries) to this inequality. They found that between group inequality was much more important than within group inequality to explain global emission inequality and its evolution.

Heil and Wodon (2000) used the same methodology to analyze future inequality in carbon emissions using business-as-usual projections to the year 2100. They considered four income groups in their study. They also considered the impact on emission inequality of the Kyoto Protocol and other mitigation measures. They found that emission inequality decreases faster than income inequality and that the reduction between groups of countries is more important than the decrease within groups to explain the evolution of overall emission inequality. Duro and Padilla (2008) employed the EGR index (Esteban et al., 1999) to analyse the polarisation in CO_2 per capita distribution across countries[2]. They found that polarization strongly decreased during 1971–2001 and that the groups of countries grouped according to polarisation optimisation leads to two groups which broadly coincided with Annex B and non-Annex B of the Kyoto Protocol. Padilla and Serrano (2006) employed the Theil index to study the development of emission inequality over time. They showed the contribution of four income groups to inequality. They showed that between group emission inequality was much more important than within group emission inequality. They used concentration indexes and showed that the concentration of emissions in richer countries —inequality when countries are ranked by income per capita— diminished less than “simple” inequality —inequality when countries are ranked by emissions per capita. Duro and Padilla (2006) explained the main driving forces of emission inequality by decomposing emission inequality into the different Kaya factors[3] (see Kaya, 1989; and Yamaji, 1991) and two interaction terms. They also decomposed inequality and its sources into between and within group components. They found that income per capita was the main factor explaining emission inequality level and development, although differences in energy intensity, which were strongly reduced during the period, and in carbon intensity of energy were also relevant. A recent work from Coondoo and Dinda (2008) incorporates more sophisticated econometric techniques[4] to outline that in the long run the distribution of emissions per capita is mainly governed by the distribution of Gross Domestic Product (GDP per capita) over time.

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[2] The concept of polarization consists in examining the degree to which the observations of a distribution are allocated around different poles and therefore form significantly homogeneous groups which are different between them. The EGR is a synthetic index of polarization developed by Esteban et al. (1999).

[3] The Kaya identity decomposition is a well known finding in the environmental economics literature by which the levels of emissions per capita is expressed as the product of emission intensity of energy (quantity of carbon per unit of energy), energy intensity (quantity of consumed energy per unit of GDP) and GDP per capita.

[4] In particular they use cointegration techniques (see Engel and Granger, 1987).

We can highlight some results and policy implications for climate policy negotiations from the literature on the distributive analysis of emissions. First, the results of the literature confirm that there are strong inequalities between the per capita emissions of different countries and world regions, although there is a clear trend to reduction of this inequality (Heil and Wodon, 1997; Padilla and Serrano, 2006). These strong differences between countries and regions have complicated the achievement of agreements in the past and will difficult future agreements, as these differences imply different interests in the negotiations. Synthetic indicators of inequality such as Gini and Theil indexes provide useful indicators of the evolution of these differences. The differences between countries are much greater if cumulative emissions are considered (Heil and Wodon, 1997). These results might support the arguments of the countries with less responsibility in causing the problem, which have been often reluctant to participate in agreements involving costs to them.

Second, there is a strong correlation between income and emission inequalities (Padilla and Serrano, 2006). Both inequalities have strongly decreased during past decades. The analysis of regions and groups of countries show that the differences between different income groups (between group component) explain most of emission inequality, while the inequality within these groups of countries (within group component) is much smaller (Heil and Wodon, 1997; Padilla and Serrano, 2006). Rich countries, which are the main responsible of climate change, are still the major contributors to the problem. The strong inequality in emission between rich and poor countries indicates that aggressive short-term measures focused on reducing emissions in rich countries might have some impact in the control of global emissions. However, some growing economies, such as China and India, have experienced a strong income and emission growth, which explain the strong reduction of emission inequality, and their participation in future agreements is essential in order to achieve an effective mitigation policy. These results reinforce the need to take into account the distribution consequences of different policy alternatives in order to facilitate the participation of the different parties in the measures.

Third, income inequality is the main driving force of emission inequality (Duro and Padilla, 2006). Moreover, if we decompose inequality in the distribution of emissions according to the Kaya identity factors, most of the decrease of emission inequality is due to the decrease of income inequality, although the strong decrease of energy intensity inequality has also been significant. The strong correlation between income and emissions per capita inequalities, and the importance of income inequality in explaining emission inequality, indicate that global policies oriented by the perspective of approaching to a fair share of atmosphere —an equal per capita emissions rights criteria— and so oriented to reduce emission inequality would be more feasible if income inequality were reduced. Policies reducing global income inequality would also lead to a reduction in emission inequality.

Fourth, the concentration of emission in richer counties has decreased less than simple emission inequality (Padilla and Serrano, 2006). This reinforces the relevance of taking into account the situations of richer and poorer countries rather than taking only into account simple emission inequality in negotiations and agreements.

Fifth, polarisation analysis shows that, although polarisation has decreased since 1971 it has not been reduced in the last years analysed (Duro and Padilla, 2008). Polarisation in 2001 was not lower than in 1997, so a distribution which leads to the formation of groups with confronting interests might still be one of the factors hampering the achievement of new agreements. Moreover, the groups endogenously obtained by polarisation analysis broadly coincide with Annex

B and non-Annex B groups of countries of the Kyoto Protocol. This result also shows that polarisation in emissions might be a relevant indicator of groups formation in policy negotiations and of the good or bad environment to form coalitions and achieve agreements.

Sixth, there are strong international differences in energy intensity. This inequality has strongly decreased in last decades, especially in some regions (Duro and Padilla, 2006). Energy efficiency gains in some developing economies have been very important and have contributed to reduce energy intensity differences between countries. Moreover, the reduction in energy intensity inequality, achieving similar levels of efficiency in countries with different income, has contributed to attenuate emissions growth. Clearly, energy efficiency gains and diffusion and convergence in energy intensity might play an important role in the future to help mitigate emissions. Technological transfers and diffusion should be important points to be taken into account in negotiations and future agreements.

Even within developed economies there has been a strong decrease of this inequality in last decades (Sun, 2002; Alcántara and Duro, 2004). According to Duro et al. (2009), in the case of OECD countries, the reduction in energy intensity differences is the main factor explaining the reduction of emissions per capita. The reduction of final energy intensity for a set of OECD countries considered in their analysis for the period 1995–2005 is mainly explained by a trend to the convergence of energy efficiency between different countries sector by sector, while an increasing sector specialization has played an opposing role. Energy-saving strategies and technology diffusion have importantly contributed to reduce and equalise the energy intensity levels sector by sector of the different countries and have lead to the reduction of energy intensity inequality observed. These results also reinforce the relevance of taking technological policies into account in future negotiations and agreements. However, a policy to this effect would not eliminate global disparities in energy intensity due to the existence of different sectoral specialisation patterns. In fact, the results show that specialisation has increasingly contributed to the energy intensity inequality between countries in the last decade.

Finally, there are also important inequalities in carbon intensity of energy. They are quite relevant for explaining differences within some regions (Duro and Padilla, 2006). This result might indicate that countries with similar income show different efforts in the change from fossil fuels to renewable energy sources. This indicates the strong potential for controlling emissions by increasing renewable energy sources and converging to lower levels of carbon intensity of energy. These differences should also be taken into account by future policies.

Among the wide amount of results that have been outlined by the previous literature three findings should be particularly considered in terms of policy relevance and for their suitability to be compared with other analysis tools (in particular Integrated Assessment Models (IAMs) as we will see more accurately in the next section):

1) Inequality in the distribution of emissions tended to decrease in the past.
2) If we create groups that are differentiated on the basis of different levels of income per capita criteria inequality in the distribution of emissions per capita is mainly composed of a between group than a within group inequality.
3) Inequality in the distribution of emissions between rich and poor countries is mainly explained by differences in the levels of GDP per capita rather than energy intensity or carbon intensity in a Kaya identity perspective.

From a policy perspective they are very important because they all provide evidence that there is a strong correlation between emissions and income distribution and that the policy agenda of equity in income distribution is strongly related to that of equity in emissions per capita distribution. An interesting research question that has been raised by the literature at a certain point is if these trends that have been identified in the past will hold in the future even if different scenarios of international environmental agreements will be implemented. The next paragraph explains what the literature about IAMs focussing on simulations says about previous results found in a context of empirical data.

3. The distribution of emissions and integrated assessment models

A recent literature has tried to connect the traditional literature about the drivers of growth with climate change issues. The seminal work by Nordhaus (1994) represented a corner stone in the literature to understand the impact of economic activities on the level of emissions and the feedback from effect from the environment, specifically from the rise of the atmospheric carbon concentration and consequently from the temperature rise to growth. The authors created a powerful tool to search the best climate policies within an uncertainty framework. Nordhaus' work created an interesting strand of research trying to implement effective tools to understand the integration between economy and environment through IAMs. IAMs represent stylized facts describing the mechanisms generating pollution in a dynamic context on the basis of mathematical and computational techniques.

Many studies have focused on some equity implications of different measures with the help of IAMs. Miketa and Shrattenholzer (2006) analyze equity implications of two burden-sharing rules ("equal emissions per capita" and "carbon intensity"). Leimbach (2003) analyses how the equal emissions per capita allocation principle influences future emissions paths and mitigation costs of different regions, taking into account permissions trade. Vaillancourt and Waaub (2004) analyse the consequences on the allocation of emissions to different regions over time of two weight sets of allocation criteria. Vailancourt and Waaub (2006) also analyze the costs for each region in each case. However, none of these works use inequality indexes or other distributive analysis tools to analyse the development of emissions distribution.

A recent contribution from Cantore and Padilla (2007) tries to fill this gap and to verify if the results arising from the empirical literature are robust over time and if more insights can be gained about the impact of future pollution stabilising policies. Any effective climate policy requires limiting global emissions. The authors investigate how the effort to control these global emissions is distributed among different regions and countries. There are several proposals on the distribution of future emission "entitlements": from those based on current emission levels or GDP shares to the distribution of "entitlements" in per capita terms, and many combinations of these. In any case, only if a global policy is perceived as fair could it lead to the necessary agreement and participation of all the relevant parties. Therefore, it becomes essential to analyze income and emission distributions, their relationship, and the consequences of different mitigation policies and scenarios on future emission and income distributions.

Cantore and Padilla (2007) use an optimal growth model to analyse emissions and their distribution under different scenarios assuming the implementation of international agreements about pollution constraints at regional level (only for Annex B countries or for both Annex B and non Annex B countries) or at global level (atmospheric carbon concentration constraint or a temperature increase constraint). Results from Cantore and Padilla substantially confirm many findings arising from the empirical literature: they confirm a strong correlation between income and emissions inequality. In other words this paper largely confirms for future trends what has been remarked for the past. Though inequality in the future decades between rich and developing countries will continue to shrink there is evidence that still emerging countries such as China and India will be far from becoming the main polluters in the near future in terms of emissions per capita and that the current status will continue to hold in the short/medium term. Of course results derive from a model and are affected by assumptions and calibration, but they seem quite robust when relevant parameter vary or (in more recent studies), when other IAMs are considered (Cantore *et al*., 2008).

The Cantore and Padilla's research leads to other results enriching analyses and findings related to the previous empirical literature. First, the results show that concentration of emission would be smaller than concentration of income for the different scenarios considered. That is, first, there is a "progressive" distribution of emissions. The "progressivity" in emission distribution decreases over time, especially in the scenarios involving a greater abatement effort in developing economies and so a higher redistribution of emissions towards rich countries. This, in the absence of economic compensations to poor countries, leads to a negative redistribution of the assimilative capacity of the atmosphere. Thus, these scenarios leading to a lower "progressivity" might be seen unfair by poor countries and undesirable from a distributive perspective.

Second, the analysis of between and within group inequality for three world regions grouped according to their income per capita shows a decrease in the "simple" emission inequality of both components for most scenarios. The results change significantly in the scenarios requiring a major mitigation effort to poor countries. In these cases the Theil index —and both between and within group components— increase. These policy scenarios seem the less appealing from a distributive point of view.

Third, when equity principles are considered for a given emissions reduction target, these principles lead to a higher abatement effort in rich countries and a redistributive effect. The redistribution is especially strong in the case of the application of the equality principle rule, although it is also significant in some cases. Although the variations of income inequality are not very relevant, it might be noticed that the application of scenarios like the Brazilian proposal[5] or the equalitarian rules[6] are the ones involving the scenarios with greater income inequality decrease. In these cases, climate policies could make a contribution to the reduction of income inequality. Clearly, these criteria would be more acceptable from a distributive point of view and more appealing for developing economies.

Finally, the impact of emissions trading policies on emission distribution depends on the structure of marginal costs for each country, on the level of global abatement reduction and especially on how the abatement effort is shared among regions. Emissions trading is a crucial mechanism governing the efficiency of policy implementation and compliance costs introduced by the Kyoto Protocol on the basis of a well known result in the literature on environmental economics claiming that the introduction of a carbon market would allow the accomplishment of a policy target with the lowest global cost. As regards its impact on distribution, it has some impact on emission inequality and a much smaller impact on income inequality. In short, this flexibility mechanism allows to alleviate the impact of the scenarios involving a stronger abatement exigency to developing countries leading to a redistribution of emissions to poor countries as regards the scenario without trade and also involves a greater decrease of income inequality. In these cases, emissions trading improves both efficiency and emission distribution and would be preferred by all parties. In contrast to these scenarios, in the scenarios considering the application of equity rules for achieving a given atmospheric concentration —which imply a strong redistribution when no trading is considered—

[5] The Brazilian proposal is a scenario widely investigated in the climate change economics literature where the sharing of the global abatement burden according to the historical responsibility in generating the temperature increase.

[6] The equalitarian rule is a scenario in which a global abatement burden is shared among regions by equalizing the levels of emissions per capita.

the results indicate that trading increases emission inequality as rich countries are the ones that buy the emission permits in this case. However, it has to be taken into account that, despite its effect on inequality indexes, emissions trade would have a positive global impact for the income of both rich and poor countries.

Summing up, we find an interesting consistency between results coming from empirical evidence and those derived from simulations data. The advantage of IAMs if compared to empirical analyses is that they are useful to implement scenario analyses based on plausible future evolutions of international environmental negotiations for policy agreements and they allow to understand the drivers of emissions distribution because of the formal mathematical equations fed by numbers extracted by reality. The great trouble concerning analyses driven by IAMs is that very often models are very different in terms of assumptions and calibration. A recent work implemented by Cantore *et al*. (2008) interestingly shows that many results such as the decreasing path of the emissions distribution over time, the predominance of the between group component and the identification of GDP per capita as main driver of emissions distribution rather than carbon intensity or emissions intensity can be extended to other IAMs. Of course much research is needed to confirm further these results.

4. Emissions distribution and the role of technology and technology diffusion

In the previous paragraphs we presented an overview of the literature on emissions distribution in terms of empirical evidence and data coming from simulations run with IAMs and we outlined the policy implications that we may extract from this abundant set of contributions. We stressed that inequality in the distribution of GDP per capita is the main determinant to explain inequality in emissions per capita. Especially IAMs can let the researcher make a step forward and understand what are the forces driving levels of GDP and its distributions between rich and poor regions and the other factors that can influence emissions distribution over time even if they are not so crucial as GDP. What emerges from IAMs is that a primary role will be played by the evolution of technology over time.

IAMs generally distinguish between two different forms of technology: industrial technology intended as Total Factor Productivity (TFP) affecting growth rates over time and environmental friendly technology affecting energy intensity through the structural change of the economies and carbon intensities reductions. The scientific literature generally deals these two kinds technology formation mechanisms as relatively equivalent. The literature about industrial technology developed earlier. After that the first contributions explaining industrial technology generated the typical Ramsey – Solow – Koopmans frameworks where technology over time evolves exogenously as "manna from heaven", a fruitful strand of research introduced endogenous technological change governed by Research and Development expenditures (R&D) and learning by doing (lbd) processes. In other words, many contributions explained technology as outcome of specific strategies devoted to promote ideas, patents, licences with the aim to increase productivity of the economic system (knowledge formation through R&D) or as outcome of learning experiences over time (knowledge formation through lbd). On the basis of this literature convergence in terms of income over time depends on two factors:

1) the speed of the process by which R&D and lbd mechanisms penetrate over time in each country.

2) the diffusion of technologies across time and across countries in terms of economies openness (imitation and learning processes) through international spillovers or technology transfer through specific programs.

These contributions explained the process of technological change as determined by an accumulation process of knowledge deriving from learning or from research and innovation according to a neoclassical scheme comparable to that describing the accumulation of physical capital. The main difference is represented between R&D knowledge and learning by doing knowledge is represented by the fact that the latter is usually represented as costless over time.

The literature about environmental friendly technological change followed that dealing strictly with industrial processes. Whereas specifically in the "industrial" literature technological change is typically shaped to affect the long run growth rate over time, in the climate change economics literature it typically decreases carbon intensity or energy intensity (Bosetti *et al*., 2006). In some cases industrial and environmental friendly technological change are present in the same model framework, in others international spillovers are introduced in order to incorporate effects of technology transfers from rich to developing countries or transboundary learning effects (Buonanno *et al*., 2003).

There are many points to understand about technological change, technology diffusion and possible effects on emissions distribution. First, it is still not clear how endogenous technological change evolves over time in different areas. Generally models include equations that are identical for rich and poor areas by implying that the mechanisms governing the knowledge formation over time are similar everywhere. Even much more obscure is the process by which technological change spreads across regions over time. Whereas for R&D investments there is wider consensus on the fact that the direction of transfer lies from rich regions to poor regions, transboundary effects of learning can be modelled as symmetric or asymmetric (Gerlagh and Kuik, 2007; Cantore, 2009). Second, for both industrial and environmental friendly technological change a consensus of the scientific evidence is still lacking on the effective capability of developing countries to learn from experience of richer countries or to use appropriately their technology. The literature about the potential of poorer regions to absorb technological change from developed areas is still slowly emerging (Bosetti *et al*., 2008). Third, it is still not clear the relationship between industrial and environmental friendly technological change. In other words, there is still great ambiguity on the fact that industrial and environmental friendly knowledge can be correlated over time (Buonanno *et al*., 2003) or should be dealt as independent processes (Bosetti *et al*., 2006). Our opinion is that there is a degree of correlation between the two forms of endogenous technological change. It is straightforward that the current technologies to capture and store carbon derive from technologies deriving from oil industries especially for what concerns pipelines. The great challenge is to verify how strong this correlation is and the modalities by which it can be expressed in mathematical and logical terms. It is reasonable to think that a higher correlation between industrial and technological change provides more opportunities for the diffusion of technologies across countries.

Fourth, a crucial issue is represented by crowing out effects that can arise in the presence of technological diffusion. As stressed by the mainstream literature, when knowledge becomes a public good that is available for all countries through technology transfers of transboundary effects this phenomenon can crowd domestic investments in technology by generating lower investments in technology for developing countries. This is one of the main interesting results found by Bosetti *et al*. (2008) when they use their IAM including international spillovers in an R&D expenditures environment.

Finally, it is difficult to understand how policies will interact to affect the process of technological diffusion. In the field of environmental technology a wide importance is assumed by flexible mechanisms for the accomplishments of emissions constraints, with a particular focus on the role played by the Clean Development Mechanisms (CDM). CDMs are mechanisms introduced by the

Kyoto Protocol by which the implementation of project such as those aimed at transferring technology from Annex B to non Annex B countries can give the right to developed countries to claim a reduction of the emissions abatement effort. As interestingly argued by Millock (2001) CDMs can be viewed by a typical principal – agent scheme in which the rich country is the principal that cannot observe the effort produced by developing countries (agent) to put into force effectively the program. This situation creates a market failure named as asymmetry informative that can be overcome by opportune policies aimed at monitoring with effectiveness the effort produced by the recipients of the programs through opportune indirect observable indicators.

In the industrial technology literature and in the environmental economics literature many contributions deal on the economic consequences of international spillovers (Barro and Sala Martin, 1995; Rao *et al*., 2006) and in general outline a positive effect in terms of policy compliance costs and growth. In some cases spillovers can generate losses when trading effects are included and spillovers generate lower energy market prices for fossil fuel exporters or when, in spatial contexts, openness can make peripheric areas of some regions still more remote or unproductive (respectively Böhringer and Löschel, 2003; Caniëls and Verspagen, 2001).

With a particular focus on the environmental economics literature no previous studies deal with the possible consequences that spillovers can generate on the distribution of emissions[7]. It is very important at this point to outline that the most important policy target in the climate change context is the reduction of emissions. The convergence in terms of emissions per capita cannot be considered per se a policy target because a context of convergence in pollution levels is compatible with scenarios incorporating very negative outcome such as high levels of atmospheric carbon concentration and temperature increase.

As outlined by Table 1, we can argue that the idea of international spillovers and convergence in terms of technological knowledge (industrial and environmental friendly) accumulation is very unlikely to contextually reduce emissions and generate a convergence in the levels of emissions per capita.

Table 1. Effects of technological convergence policies on the reduction of emissions and on the convergence in terms of emissions per capita.

	Reduction of emissions target	**Convergence in emissions per capita**
Industrial technological convergence	An industrial technological diffusion promotes growth in developing countries and more emissions	Convergence in terms of output per capita and emissions per capita
Environmental friendly technological convergence	An environmental friendly technological diffusion promotes an emissions reduction driven by developing countries	The gap in terms of output per capita and consequently in terms of emissions per capita does not shrink as the abatement technologies of rich and developing areas are similar

As we outlined in the previous sections, inequality in the distribution of GDP per capita governs the path of inequality in terms of emissions per capita. In a scenario involving convergence in the levels of income per capita we should also expect a lower gap between developed and developing countries in terms of emissions per capita, but also a higher level of emissions because of the higher levels GDP per capita for developing countries. On the other side, a technological convergence in

[7] A work in progress paper by Cantore *et al*. (2008) outlines that in a model including endogenous technological change, international spillovers do not widely affect the distribution of emissions. Even if these results are already quite interesting because they signal that spillover could not be drivers of convergence across regions, more research is needed to confirm the results with different models assumptions and calibrations.

abatement technologies should reduce emissions, but, in a context of higher levels of income per capita for rich regions, this would not reduce the gap in terms of emissions per capita. In other words, a scenario presenting an effective reduction of greenhouse gas emissions and equality in the distribution of emissions per capita is a desirable situation that is feasible only in scenarios where convergence in industrial and environmental friendly technological change will be jointly pursued. This is a challenging issue to investigate from which it could depend the right coordination of growth, equity and environmental policies.

Moreover, we point out that a scenario presenting convergence in income per capita and emissions per capita and convergence in abatement technologies could not generate a satisfactory emissions reduction to tackle global warming as, even in a convergence path of industrial and environmental friendly technology, the industrial technological change could enhance growth more than what environmental friendly technological change reduces emissions in each country. Reconciliation between emissions reductions policies that stabilize or decrease the path of pollution and emissions per capita convergence options is compatible with a scenario in which income and emissions levels are delinked. The EKC literature stresses that the relationship between levels of income per capita and emissions per capita is governed by three factors: the scale effect governed by the increase of economic activities that rises emissions; the technical effect that reduces emissions through technologies reducing carbon intensity; and finally the structural change effect reducing emissions through the decarbonisation of the economy driven by the transition from fossil fuel to fossil free economies.

The EKC literature stresses that for CO_2 the scale effect increasing emissions dominates the technological and the structural change effect by generating an increasing path of the income-emissions relationship. As we have seen before, this finding is confirmed by the inequality literature stressing that differences in the levels of income per capita govern differences in emissions per capita.

Our opinion is that the pursue of the emissions reducing and convergence in emissions per capita targets is compatible with future scenarios in which the technological and the structural change effect will dominate the scale effect and convergence in terms of GDP per capita for developing countries will be reached by harmonized green paths of growth among countries. For this purpose, as outlined before, it will be interesting to address the research to directions aimed at investigating synergies between technological change developed for “industrial” purposes and environmental friendly technology purposes.

Conclusions

In this paper we explained a new strand of research that is arising from climate change economics literature about the study of the international distribution of emissions per capita and its determinants. We stressed that whereas there are already some contributions dealing with this topic by investigating evidence about past trends, a new field of analysis concerns the study of the future evolution of emissions distribution over time.

Interestingly we argued that results concerning the past distribution of pollution generation at international level arising from the empirical evidence and those coming from simulations obtained by IAMs according to scenario analyses are consistent for many reasons. In fact past and “future” evidence both agree about a decreasing path of emissions per capita inequality over time, about a predominance of the “between group” component of inequality in the distribution of emissions when we analyze groups according to different income per capita levels and about the fact that GDP per capita rather than carbon intensity or emissions intensity is the main determinant to explain differences in emissions per capita between rich and poor regions. In particular, IAMs and empirical evidence agree on the fact that inequality in the distribution of income governs inequality in the distribution of emissions. From a policy point of view this finding is particularly interesting as it implies that the policy agendas about income and emissions distribution are strictly connected.

Moreover we explained the role that technological change will play in relation to targets concerning income and emissions distribution and specifically we made a distinction between technological change aimed at industrial development or at environmental friendly methods of production. We outlined that targets concerning income distribution, emissions distribution and emissions reduction will be likely to be in conflict as scenarios involving a convergence in income could heavily increase emissions and scenarios spreading abatement technologies would fail to reach an equal distribution of emissions per capita if income convergence were not possible.

The “first best” scenario would be that in which convergence in income per capita and diffusion of industrial technology are jointly reached and in which levels of emissions are delinked to the levels of income. In other words from a policy perspective the best scenario is the one in which there is wide international diffusion of industrial and environmental friendly technology and in which industrial technological change progressively generates opportunities to set up environmental friendly technological change. This is a very optimistic scenario that will very unlikely occur. Rather, policy makers should be prepared to tackle conflicting targets, but often they are not appropriately supported by research. The policy relevance of the EKC hypothesis is quite weak, because it is a concept dealing only with two policy dimensions: economy and environment. As mere example it does not say anything about the welfare levels that are associated to each income-emissions possible path. For this reason the EKC hypothesis represents an inappropriate tool to tackle sophisticated and articulated policy targets. Policy makers should be supported by scientific tools that take into account a wider set of policy targets. Multicriteria analysis in this context is an interesting tool (Janssen and Munda, 1999), but also the inequality literature referring to Atkinson’s (1970) and Sen (1976) represents an interesting strand of research to deal trade off and complexities[8]. The way towards the reconciliation between science and policy is still ongoing, but fruitful directions exist and should be pursued with more effectiveness.

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[8] In particular they create indices dealing with scenarios presenting tradeoffs between income and income distributions, but they could interestingly be extended to incorporate other policy dimensions.

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