How Production Based and Consumption Based Emissions Accounting Systems Change Climate Policy Analysis: The Case of CO2 Convergence

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Abstract

Much of the existing research analyses on emissions and climate policy are dominantly based on emissions data provided by production-based accounting (PBA) system. However, PBA provides an incomplete picture of driving forces behind these emission changes and impact of global trade on emissions, simply by neglecting the environmental impacts of consumption. To remedy this problem, it is proposed to calculate national emissions based on consumption-based accounting (CBA) system. In this article we question the relevance of PBA's dominance. To this end, we, firstly, try to assess and compare PBA with CBA adopted in greenhouse gas emissions accounting systems in climate change debates on several issues and to discuss the policy implications of the choice of approach. Secondly, we investigate the convergence patterns in production-based and consumption-based emissions in 35 Annex-B countries for the period between 1990 and 2015. This study, for the first time, puts all these arguments together and discusses possible outcomes of convergence analysis by employing both the production and consumption based CO_2 per capita emissions data. The empirical results found some important conclusions which challenge most of the existing CO_2 convergence studies.

Keywords: Consumption Based Accounting, CO_2 Convergence, Climate Policy, CO_2 and Trade, Annex B Countries

1. Introduction

After two decades of contentious and exhaustive debates, the parties finally have reached a climate deal at the 21st of Climate Summit in 2015, which marks a major step forward to averting climate catastrophe. In order to achieve the long-term climate goal, the Paris Agreement emphasize that it is necessary to peak global greenhouse gas (GHG) emissions in early 2020s and global economy becomes carbon neutral by the end of the century (IEA, 2017). With the Paris Agreement, all countries participated in efforts to reduce GHG emissions under the principle of common but differentiated responsibilities **(**CBDR). Based on these principles, while most of developed countries have taken absolute reduction targets, other countries have had commitments based on intensity and deviations from Business as usual (BAU) targets. Some countries proposed objectives are generally on track to achieve their targets that they have pledged at the Paris Agreement, yet it is not sufficient to meet 2^c target objective. In other words, there is significant inconsistencies between science-based targets and national commitments as current plans committed for the Intended Nationally Determined Contributions (INDCs) will lead to earth's warming to 2.7^c-3^c (Climate Action Tracker, 2015; IEA, 2015).

Among the GHGs, carbon dioxide (CO_2) has the largest share and main causes of CO_2 emissions are due to the burning of fossil fuels. Therefore, due to its relevance to climate policy and growing concerns about carbon leakage and competitiveness, the reduction of CO_2 emissions are one of the most important objectives at a global scale.

Research on climate policy and emission issues has been very profound and covers many different topics. Accurate assessment of anthropogenic CO_2 emissions and their distribution across the countries is important to better understand the global carbon cycle, support the development of climate policies, and project future climate change.

Assessing CO_2 emission developments both in total and per capita emissions will provide several useful insights to policymakers. However, it is equally important to notice that how emissions are calculated as different accounting approaches could usually provide different outcomes. Much of the existing research analyses on emissions and climate policy are dominantly based on emissions data provided by production-based accounting (PBA) system as national GHG emission inventories take a production perspective, where emissions are allocated to the country and when the emissions actually occur. Emissions calculated by production based (PB) mechanism, however, provides an incomplete picture of driving forces behind these emission changes and impact of global trade on emissions, simply by neglecting the environmental impacts of consumption. It is therefore raised some controversies as an accounting mechanism. To remedy this problem, it is proposed to calculate national emissions based on consumption-based accounting (CBA) system, under which a country's national responsibilities for GHG emissions reduction is measured in its consumption rather than emissions generated from production (Peters and Hertwich, 2008). This study argues that many of the analysis could be misleading or incomplete only relying on data provided by PBA as it ignores trade perspective. Many studies on climate policy, including distributional issues in GHG emission reduction commitments, Environmental Kuznets Curve (EKC), decoupling and carbon leakage issues as well as discussions on effectiveness of climate policies may have different considerations when analyses are made with the CBA rather than the PBA.

The objectives of this study are many fold. First, the study tries to assess and compare consumption based (CB) perspective with current PB perspective adopted in GHG emission accounting system in climate change debates on several issues and to discuss the policy implications of the choice of approach. The second aim of the study is to shed a light on pollution and economic growth with convergence analysis by separately estimating the familiar cross-sectional regression with per capita CO_2 emissions data calculated with the CB and PB accounting systems.

This study particularly discusses and analyses the convergence in CO_2 emissions with a focus on how the outcome differs when consumption based emissions (CBE) are taken into consideration. As almost all literature on CO_2 emissions convergence employs data based on standard production perspective, it can be argued that such assessments could be incomplete and need further insight with the CBE. Assessing existence of convergence with the CBA data could identify unintended outcomes of PBA approach and helps to develop new policies according to these needs. Main contribution of this study is to become the first analysis that considers both the CBE and production based emissions (PBE) in emission convergence literature.

The organization of this paper is as follows. After the introduction, next section will discuss the differences in between the PBA and CBA approaches and how adopting these particular emission approaches changes the understanding of emissions and its relevance on climate policies. Then, the study empirically applies and compares the results of both the consumption and production based CO_2 emissions per capita on convergence analysis for the Annex-B countries. The final section discusses policy considerations and ends with conclusion.

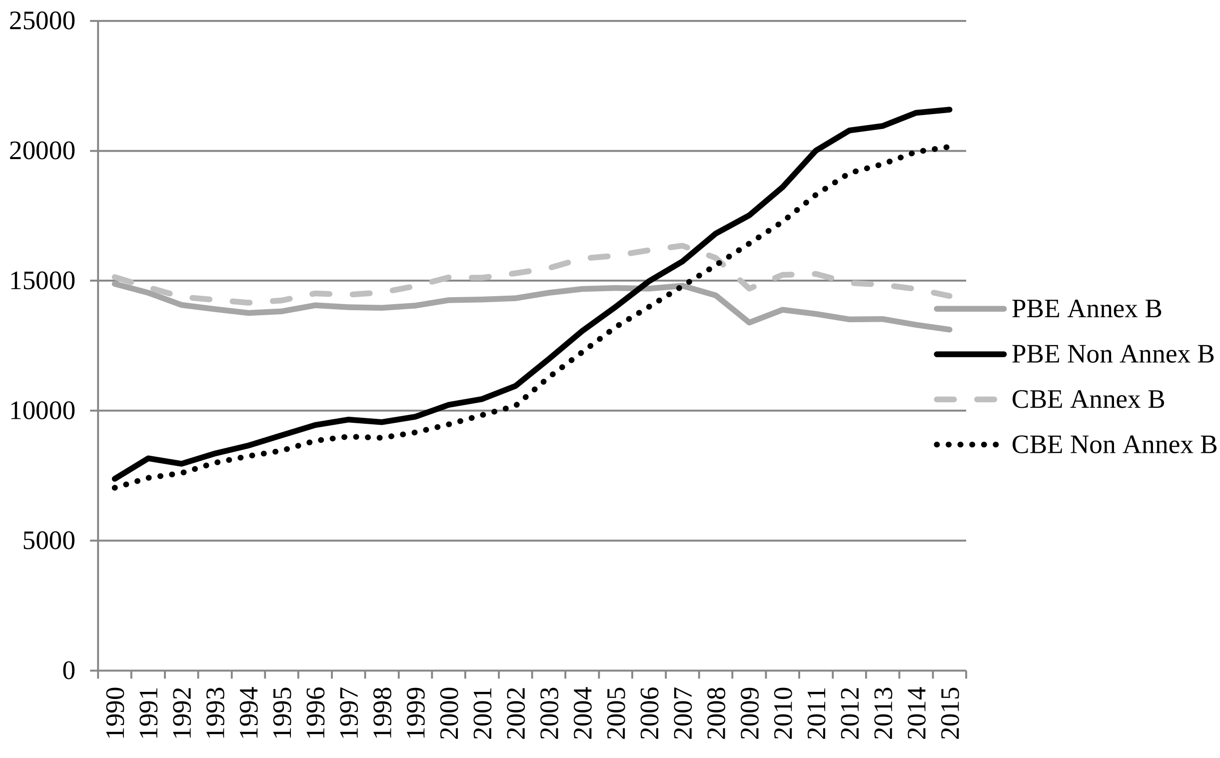
2. Emission Accounting Systems: PBA and CBA

In this section, we will discuss main elements of different emissions accounting systems and then briefly consider how these two approaches might have an influence on climate policy discussions such as distributional issues in GHG emission reduction, commitments in international climate negotiations, carbon leakage issues, decoupling as well as effectiveness of climate mitigation policies. It is eventually argued that any analysis on these issues might have different outcomes depending on data used based on these two approaches.

There are mainly two different approaches in measuring human induced GHG emissions: The PBA and CBA. PBA (territorial) calculates emissions that are generated from the domestic production of goods and services irrespective of whether they are consumed domestically or are exported. Since the Kyoto Protocol and its follow up agreements, including the recent Paris Agreement, countries are required to prepare their national GHG emission inventories based on the PBA (Afionis et al., 2017). This approach, however, have been criticized as it does not take into account the international emission flows in the form of goods and services that have been produced in one country and consumed in another one. Emissions embodied in trade are significant part of the global emissions as recent studies estimated that up to 25-30% of global emissions are generated from such operations (Zhang et al., 2017; Davis and Caldiera, 2010; Peters and Hertwich, 2008). Therefore, recent studies suggest that in order to better understand environmental footprints, CBA should be applied as it attributes all emissions, directly and indirectly, occurring along the production chain to the final consumer of the products (Tukker and Diezenbatch, 2013; Peters et al, 2016). Main difference between the PBA and CBA is the distribution of the CO_2 trade balance between two trading partners. The PBA generally provides significant advantages to the countries, who have outsourced their emissions to some developing countries. This outcome particularly raises some objections from countries hosting emissions intensive exporting industries, who argue that the importers of emission intensive goods should bear the responsibility (Dobson and Fellows, 2017). The gap between embodied emissions in imports and exports might be due to the increasing gap between the trade volume of import and export as well as changing the trade patterns. If a country experiences a huge trade deficit, where imports exceeds their exports, it is more likely that this country will have a higher CBE than PBE. If, on the other hand, the country dominantly exports energy intensive products and imports less energy intensive products in their trade, it is possible to see that this country's CBE are lower than PBE.

As the global trade volume and international integration of supply chains have been growing significantly in past decades, it is fair to expect the emissions calculated by different approaches will also differ. Consequently, while some countries benefit from this outcome the others might be disadvantageous. It is therefore important to see how emission trends have been evolving based on these two approaches. For this purpose, we begin with analyzing developments in total CO2 emissions for the Annex B and Non-Annex B countries.

Figure 1: PBE and CBE in Annex B and Non-Annex B Countries (1990-2015)

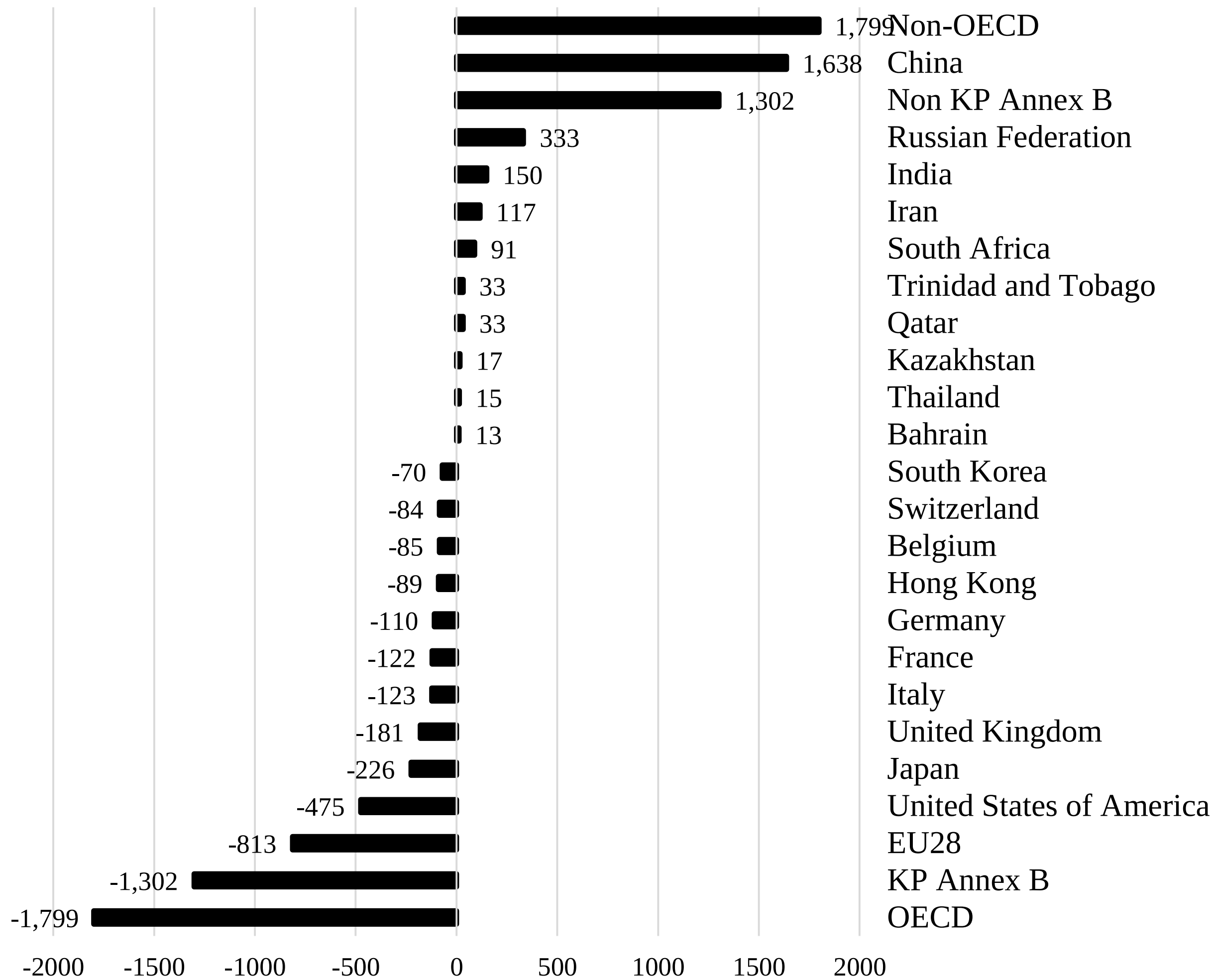


Source: Global Carbon Atlas, http://www.globalcarbonatlas.org/en/CO2-emissions

According to Global Carbon Atlas data, which calculated both PBE and CBE for the period of 1990 to 2015, total CO_2 emissions in Annex B countries have stabilized in past two decades. This has been the case for both PBE and CBE. Non-Annex B countries' emissions, however, have been on the rise and total emissions caused by Annex B countries are overtaken by non-Annex B countries in 2005 for the PBE and 2008 for the CBE. As can be seen from Figure 1, while Annex B countries' CBE have always exceeded the PBE, the opposite has been observed for the Non-Annex B countries. This implies the fact that the Annex B countries are net carbon importers and generate emissions savings through international trade. The Non-Annex B countries, however, are net carbon exporters, which indicates that these countries produce more emissions domestically than they require for their own final demand consumption (Fan, et al, 2016).

A closer look at the data on emissions, it is important to see that, while until 2007, the gap between PBE and CBE widened significantly, the trend following the economic crises has reversed and the overall gap has been declined to a certain level for both Annex B and Non-Annex B countries. Specifically, after the global financial crises, while both the CBE and PBE for the Annex B countries have declined, the reduction in CBE has particularly exceeded that in production between 2008 and 2015. On the other hand, according to Global Carbon Atlas data, increases in CBE have been consistently higher than the PBE for the Non-Annex B countries for the same period. There are various factors behind these recent improvements in global emissions, which should be considered from both consumption and production perspective. As countries mainly focused on domestic activities during the global financial crises, the global economy experienced a large drop in international trade, which resulted in a decrease in embodied emissions in trade (Grubb et al., 2016; Pan et al., 2017). The large decline in CBE after the global economic crises in developed countries are explained by the fact that, during the recession periods, household savings increase while consumption expenditures decrease due to the precautionary reasons (Mir and Storm, 2016). If such trend persists, this will have significant implications for the CO_2 emissions and hence for the climate mitigation policies.

Figure 2: Major CO_2 Emission Exporters and Importers in 2015



Source: Global Carbon Atlas, http://www.globalcarbonatlas.org/en/CO2-emissions

If the emissions embodied in the exports of a country exceed those embodied in its imports, then the country will be a net emission exporter. On the other hand, if the emissions embodied in the imports of goods and services exceed the emissions embodied in the exports, then the country will be a net emission importer. Figure 2 illustrates major emission exporters and importers for 2015. As can be seen from Figure 2, mainly developed countries and group of developed countries (the OECD and the EU) are major carbon importers. Most of the developing countries are the carbon exporters. The net emission transfers from OECD countries to non-OECD countries increased from 0.4Gt CO_2 in 1990 to 1.8 Gt CO_2 in 2015. As developed countries generally have high per capita income, this enables their households to spend more on consumption. The increasing consumption of goods in these countries has largely relied on production of developing countries, which resulted in outsourcing environmental impacts to developing countries. However, it is worth noting that there are considerable exceptions to such generalizations. For instance, some of the developed countries such as Australia, Netherlands and Canada, who are mainly fossil fuel exporters, are generally net carbon exporters. Besides, majority of the least developed countries and some of the developing countries –such as Brazil, Mexico and Turkey are net carbon importers. China remarkably singles out itself as being the largest carbon exporter, where its traded emissions exceeds the non-Annex countries combined, where China is a member of this group. It is also important to note that even though some of the countries' total emissions transfer figures might be small in absolute terms, the percentage of the traded emissions could make up a significant part of total emissions of that country. For instance, France, as a net carbon importer, has total emissions embodied in trade that reaches up to 33% per cent of their total CO_2 emissions. According to OECD report, while CBE in OECD on average were %16 higher than the PBE, some of the more advanced members, such as the United Kingdom and Sweden, CBE are up to %30 higher (OECD, 2013), Global Carbon Atlas data also indicates that, similar to PBA data results, the emissions calculated by the CB principle did not change the ranking of major carbon emitters, yet the gap between the countries have been widened over the years (Fan, et al., 2016).

As can be seen further below analysis, the CO_2 per capita emissions are also significantly differs when accounting system is changed, where PBA indicates relatively lower per capita emissions for developed countries compared to the CBA data. The reverse is usually the case for developing countries.

3. Role and Impacts of the PBA and CBA on Climate Policy Analysis

Above mentioned differences in CO_2 emissions calculated by both PBA and CBA clearly illustrates that international trade and emissions embodied in trade cannot be ignored while determining the underlying driving forces behind global, regional and national emissions (Liddle, 2018; Mir and Storm, 2016). In this regard, alongside PBA, considering CBA will provide several useful insights into the GHG emission analysis. Besides, making a distinction between the

CBE and PBE will have several implications and address some important policy considerations (Sato, 2012). In this section, we will briefly discuss how economics and political perspective may differ on current analysis on GHG emissions when recognizing the role of consumption in global emissions by adopting CB perspective.

3.1. Impacts on Climate Negotiations

As mentioned earlier, national GHG emission inventories are officially calculated with the PBA system since the Rio Convention. Selecting different GHG accounting systems may have an important impact in defining binding commitments across countries during the climate negotiations (Boitier, 2012). The PBA generally provides significant advantages to the countries, who have outsourced their emissions to some developing countries. This outcome particularly raises some objections from countries hosting emission intensive exporting industries, who argue that the importers of emission intensive goods should bear the responsibility. It is argued that the eventual realisation of CBA will more likely have the ability to resolve some of the sensitive issues encountered in global climate debate. If adopted by the UNFCCC, CBA particularly provides a flexible approach to the parties and shed lights on trade related emissions as well as design of alternative mitigation policies (Amador et al., 2017). In fact, it is argued that the adoption of CBA as a target base in international negotiations may have potential advantages of fairness, cost and effectiveness as this accounting system can transform the issue of the distribution of responsibility for emissions across countries into a self-enforcing situation of fair and cost efficient global coordination, which would eventually improve the overall effectiveness in terms of GHG emission reductions (Dobson and Fellows, 2017; Grasso, 2016). Emission reduction responsibilities would be higher for some of the developed countries, if the responsibilities were assigned according to the CBA system. For the developing countries where the CBE is lower than the PBE, the CO_2 per capita would be lower and thereby the responsibilities for these countries would also be less.

It is also argued that if the objective of environmental goals are clear and the concerned pollutants are global, measuring emissions through CBA system is analytically the most appropriate tool to monitor and assess the impacts and policy responses (OECD, 2011; Peters et al., 2016). This clearly matches with the objectives of climate mitigation as GHG emissions are global pollutants and there are certain and clear targets in recent Paris Climate Agreement such as reducing emissions to be neutral after 2050.

It is important to note that Post-Paris negotiations cannot be successful to secure more ambitious reductions without an equitable distribution of responsibility. As set out in the Paris Agreement text, this will be achieved by periodic review, known as “global stocktake”. The Paris Agreement mandates that the global stocktake should be undertaken in a comprehensive and facilitative manner, in light of equity and the best available science[1]. During these global stocktakes, in order to improve the transparency and clarity of information to facilitate the assessment of collective progress, CBA could be considered as one of the main accounting systems to better track the emissions and its sources (Grasso, 2017). If Post-Paris Agreement negotiations adopt CBA as a supporting system, then, new considerations and adjustments are needed following these changes. As a result, studies focusing on emissions allocation, burden sharing and equity issues have to reconsider their assessments on entirely new data sets, such as emissions both total, sectoral and per capita emissions, calculated by CBA.

3.2. The Impacts on Decoupling, Leakage and EKC Analyses

Global energy-related CO_2 emissions from fossil fuels and industry were flat for the third consecutive year in 2016 even as the global economy grew (IEA; 2017). This minimal increase of 0.2% in global emissions illustrates a divergence of the trend of 2.2% average growth during the previous decade, signaling a continuing decoupling of emissions and economic activity. According to many studies, recent trends in carbon reduction illustrate success of developed countries efforts in terms of decarbonisation and decoupling. Achievements in recent GHG emission reductions were considered mainly due to the growing deployment of renewable energy, improvements in energy efficiency as well as structural changes in the global economy (IEA, 2017). This success story should be questioned as current PBA system does not account for exported emissions in their CO_2 data. Therefore, even if decoupling is observed for some of the developed countries, the result should be approached cautiously as this outcome might also be due to the leakages (Davis and Caldeira, 2010; Wiebe and Yamano, 2016). That is, energy intensive manufacturing production from developed countries might have shifted to developing

[1] For the Stocktaking process and long term objectives of the Paris Agreement, see http://www.wri.org/blog/2017/05/insider-designing-global-stocktake-under-paris-agreement-catalyst-climate-action

countries. In a fragmented climate policy regime, as we have seen in the cases of the Rio Convention and the Kyoto Protocol, it is highly likely that pollution intensive industries will contract in countries with relatively strong environmental regulation and expand in those where there is none or relatively weak environmental regulations. (Copeland and Taylor, 2013). This outcome will result in carbon leakage. Some studies, for instance, estimate that binding commitments under Kyoto Protocol have increased committed Annex-B countries' embodied carbon imports from Non-Annex B countries by almost %8. Ignoring the leakage issue will create a false sense of achievement and misinformation for the public and policymakers. By using PB approach, it is not possible to detect the carbon leakage occurring from developed countries to developing countries. This emphasize the importance of considering alternative emission calculations and new policies and perspectives based on CBA as this approach can help to identify cases of carbon leakage and policy efforts for prevention (Peters et al., 2016; SEI, 2017).

Related to decoupling and carbon leakage issues, a similar line of studies focus on emissions and economic growth relation through so–called Environmental Kuznets Curve (EKC) hypothesis, which implies that economic development in the early stages leads to a deterioration in the environment, but after a certain level of economic growth such deterioration slows and decreases further. Even though empirical evidences on growth and carbon emissions show mixed results, numerous studies found that the inverted U shape EKC is particularly valid for many developed countries (Mir and Storm, 2016). Major drawbacks of these studies, however, are to use PBE data in their analysis (Aşıcı and Acar, 2016; Mir and Storm, 2016). It is argued that many of developed countries have reduced their emissions thanks to partially outsourcing these emissions to developing countries. As a result, the EKC analysis could illustrate the GHG emissions are reduced as the countries become richer without changing their unsustainable consumption patterns (Aşıcı and Acar, 2016). Therefore, the EKC analysis by using PBA data may not be reliable and requires such analysis to be tested also with emissions data calculated by the CBA. Recent studies considering CBE when testing the EKC hypothesis found that reaching the turning point in the relationship between income and emissions requires very high income per capita and take decades to arrive that point, which will overshoot the critical 2^{c} level (Mir and Storm, 2016). This illustrates that the issue of delinking of economic growth with emissions should be reconsidered carefully by adopting CBA data, otherwise such arguments could be misleading as cleaning environment at home does not guarantee an overall reduction at global level. In the case of a complete global agreement on GHG emissions, however, this issue could be relatively irrelevant as one expects there will be no room for carbon leakage.

3.3. Impacts on Climate Mitigation Policies

Designing effective and appropriate policies and measures to reduce GHG emissions are at the core of climate and environment policy. Most of the current climate mitigation policies adopt territorial based regulations which eventually takes PBA perspective (Peters et al., 2016). To ensure a more equitable, fair and swifter transition to a low carbon future, current PB policies alone are not adequate to limit global emissions (Scott et al., 2016). Identifying emissions based on CBA and distinguishing the embodied emissions in trade will provide clear and fair information whether designed policies and measures lead to real reductions in GHG emissions or relocation of industry and emissions to countries with no regulation. If CB perspective considered in policymaking as a main accounting system, then the policy should specifically focus on household consumption patterns and international trade (Hubacek, 2016). Accordingly, this will require relevant knowledge, infrastructure and resources to change household behavior towards low-carbon society (Brizga et al., 2017). As a result, CBA provides new perspectives on existing mitigation policies and presents an opportunity to address emissions embodied in trade. When consumption and trade related emissions are targeted, policy-makers become more likely to adopt more comprehensive policies, as it becomes more essential to accompany a set of policy mechanisms addressing demand, trade and business supply chains (Scott, 2016). For instance, in order to avoid leakage problem, climate policies should focus on by directly addressing embodied emissions in trade and resource use in final consumption. For this purpose, it is argued that taxing the carbon footprint could be more advantageous than the unilateral carbon pricing, as such unilateral climate policy induces carbon leakage through the relocation of emission-intensive and trade-exposed industries to regions without emission regulation (Böhringer et al., 2017). In this respect, in addition to current PB perspectives, new policies such as eco-labelling, consumption tax on carbon contents etc., will become increasingly important when attention is given to domestic consumption.

Energy and emission related indicators can be used to measure and evaluate environmental impacts as well as effectiveness of policy measures to tackle these impacts. Setting up sustainability targets and monitoring their progress through indicators are particularly important with respect to policy response. In this regards, emissions indicators calculated with production perspective is insufficient and needs CB approach alongside as it is a more convenient way of measuring sustainability by taking into account both the direct and indirect impacts of consumption. Therefore, another argument to support for adopting CB perspective in emission accounting is to set up more specific and focused emission indicators for a better understanding of the dynamic changes of CO_2 emissions and to provide necessary information for policy making. CBA should be considered as a complementary to the PBA, rather than as a substitute as different emission inventories have different system boundaries which will place focus on alternative mitigation strategies[2]. With the CBA system, it is possible to identify new policy interventions and increase the potential to break down barriers that exists between developed and developing countries in international climate policy (Scott and Barrett, 2015).

4. Convergence Studies on CO_2 Emissions

Another line of research emerged in climate change- economic growth literature focused on convergence in emissions. By highlighting two earlier research lines, that investigate per capita income convergence among countries on the one hand, and the relationship between the wealth and environmental degradation, so-called EKC on the other hand, Strazicich and List (2003) presented the first study on convergence on CO_2 per capita, arguing that there is a potential gap in the literature and needs to be investigated whether spatial emissions among countries have converged. By doing so, it is believed to provide a link between the empirical literature that correlates pollution and incomes and the literature that finds spatial incomes have converged through time (Karakaya et al., 2017). Following Strazicich and List, further studies argued that investigating per capita emission convergence among countries are important for globally, both for developed and developing countries. The fast growing literature analysed many different aspects of $\mathrm{CO_2}$ per capita convergence ranging from different policy perspectives for different group of countries and different time periods.

Understanding the evolution of CO_2 emissions and CO_2 per capita of all countries should be useful for policymakers. There have been many studies in the literature that evaluate the gaps in per capita emissions between countries and consider distributional issues related CO_2 emissions.

[2] For a detailed discussion on CBA and mitigation policies on European Union, see the project website at http://carboncap.eu

For this purpose, convergence in emission per capita received greater attention by many of those studies (Yavuz and Yılancı, 2016; Barassi et al., 2017; Kıran and Baygın, 2017). Examining convergence patterns in cross-country emissions, it may be possible to receive some important information, which will provide some useful insights for climate policy. The main motivation for studying emission convergence is that convergence in per capita terms could influence the political economy of negotiations in international climate regime (Aldy, 2006).

In terms of equity issues, many effort sharing approaches consider emission per capita as a principal basis. That is, by giving an equal emission rights to pollute, each individual eventually converges their emissions amount over the time. This assumes that developed countries per capita emissions stabilize or decrease, while emissions per capita in developing countries gradually increases (Criado and Grether, 2010). If per capita emissions among countries diverge, allocating emissions through on per capita basis would be more costly as it would result in substantial amount of international transfer rents through carbon allowance trading. Developing countries will be less likely to agree on emissions reduction obligations if there is no convergence in per capita emissions. In the case of emission convergence globally, however, the magnitude of rent transfers would be reduced, and accordingly, adoption of international agreement could be more acceptable by all parties (Aldy, 2007; Brannlund et al., 2015). Development in CO_2 per capita emissions also provides significant information on the performance of policies and measures applied by individual countries. In this respect, convergence in emission per capita is a key concern for policymakers as it provides knowledge of what can be expected concerning future convergence at the global scale, by analysing evolution of past trends in emissions per capita (Sato, 2012). Relevant to effectiveness of mitigation policies, many climate change models projecting future emission scenarios assume that the emissions are converging over time (Zhou and Wang, 2016). Therefore, investigating convergence patterns in CO_2 emissions becomes essential as it is important to see whether these assumptions are accurate or, at least, whether there is a trend in GHG emissions in this direction (Barassi et al., 2011).

Empirical studies on CO_2 emission convergence find mixed results and the results largely depend on the sample taken into account and the technique used. Recent reviews on CO_2 emission convergence literature indicate that while many of global scale studies show divergence in emissions per capita, there is usually convergence in per capita emissions among majority of developed countries (Petterson et al., 2014).

As mentioned above, convergence analysis on per capita emissions could reveal many important insights regarding climate policies. A major limitation of available convergence studies is that they all focus on the PBA perspective and fail to consider the role of consumption perspective, where it is main driving force that affects GHG changes.

This study objects some of the arguments with respect to interpretation of the convergence results such as mentioned in above literature. Convergence studies on CO_2 or GHG emissions usually suggest that, if there is convergence observed among countries, it is plausible as countries equity issues are minimized (Barassi et al., 2017). This study argues that even though a convergence pattern is empirically found in CO_2 emissions across countries with the PBA data, policymakers should be cautious with such outcome as the result may well mean that emission reduction burden is outsourced by developed countries to developing countries. As can be seen, the issue of carbon leakage and trade play a key role in our discussions, such that the PBA system does not account for the occurrence of relocation of emission intensive and trade exposed industries from developed to developing countries. In this regard, we claim that emission convergence analysis should be reconsidered by using new dataset calculated by the CBA. By doing so, new insights could emerge and some ignored aspects of emissions and economic growth could be more strongly highlighted. In parallel to the above mentioned arguments regarding impacts of emissions accounting on several climate policy issues, we believe that convergence analysis studied with the PBE and CBE could be discussed with the similar arguments, where we will turn in the next section.

With regard to equity and fair share, using CB perspective is believed to be more advantages than the PB perspective in climate negotiations for two reasons. First, in terms of a fair share, per capita emissions are best characterized with the CBA as whoever consume goods should also share the responsibility. As an end user, the consumer should be held responsible for the goods that he/she consumes whether produced domestically or imported. However, if a product produced within the territory yet exported abroad, in this case, the emissions associated for this product should be under foreign consumers' responsibility rather than the exporting countries'. This fact however is not fully reflected in current climate discussions as all studies analysing convergence in production based CO_2 emissions per capita. The producing and consuming countries responsibilities should be differentiated and this can be properly measured by CO_2 per capita based on CBA (Liu et al., 2015). Secondly, any convergence studies using per capita emissions based on PBA could be misleading if there is leakage issues. If the leakage is taking place, for instance, it is not unreasonable to expect a regional or global convergence as developed countries per capita emissions will be lower and unmitigated developing countries emissions will be higher. One needs to see CO_2 per capita emissions calculated by CBA are also converging. Otherwise, it is possible that the emissions are outsourced and carbon footprints for developed countries have not improved. It is therefore important to cross-check this outcome by analysing convergence with CBA CO_2 emission data alongside with the PBA ones.

Once again, by giving reference to the leakage issues, it is possible to have some understanding of the emissions convergence and decoupling relationship. It can be argued that any assessment in convergence analysis cannot provide significant information with respect to decoupling discussions when analysis is made only by using PB emission data. If we find convergence by using both data sets, then, it is possible to claim that decoupling is truly taking place as CBA proves that the leakage issue is minimised. Using both PB and CB accounting data also helps to identify whether improvements in emissions and in decoupling are due to the designed mitigation policies or to the outsourcing of production (Wiebe and Yamano, 2016).

Even though, EKC and emissions convergence have been analysed separately for long time, it is argued that they are closely related (Martino and Nguyen Van, 2016). If the argument of EKC holds true, this will consequently result in a convergence in emissions between the developed and developing countries since we will see a decrease in emissions while developed countries continue to grow and developing countries emissions will increase as they experience economic growth (Martino and Nguyen Van, 2016). On the other hand, if there is no proof of EKC, the emissions may or may not converge by depending on other factors. Some studies found that the existence of EKC for some of the countries could occur simply due to the existence of pollution heavens (Kearsley and Riddel, 2010). Cole (2004), for instance, found that existence of EKC for the North and South regions of the world are due to the outsourcing of the emissions by the North towards the South regions. It is therefore, it can be argued that if the empirical study finds the EKC by using PBE data, the convergence may not be found if the convergence analysis used

CBE data. This highlights the importance of using CBE data as reliable analysis on EKC dependent on the correct using of the data sets.

4.1. Methodology, Data and Findings

(i) Methodology

In order to estimate absolute and conditional convergence in CO_2 emissions measures, we use the familiar cross-sectional regression tests in the tradition of Mankiw, Romer and Weil (1992) and Strazicich and List (2003). A generic representation of this regression used by Mankiw, Romer and Weil (1992) to estimate income convergence is as follows:

$$\gamma_i = \alpha + \beta lny_{i,0} + \varphi Z_i + \varepsilon_i \tag{1}$$

where γ_i denotes the growth rate of income between 0 and t, $lny_{i,0}$ is the initial value of income, α is a constant term, β is convergence parameter, Z_i denotes the control variables and ε_i is an error term. Eq. (1) is transformed to the following specification by Strazicich and List (2003) to test CO_2 emissions convergence[3]

$$\gamma_i = \alpha + \beta lnCO_{2_{i,0}} + \varphi Z_i + \varepsilon_i \tag{2}$$

where α, β, Z_i and ε_i are the same as in Eq. (1). In Eq. (2), dependent variable is the annual growth rate of per capita CO_2 emissions and $lnCO_{2_{i,0}}$ denotes the initial level of per capita CO_2 emissions. Eq. (2) tests the following hypotheses: while $\varphi = 0$ and $\beta < 0$ implies absolute convergence, $\varphi \neq 0$ and $\beta < 0$ suggests conditional convergence. Thus, when no control variables are included, the absolute β convergence is tested, simply by regressing the average annual growth rate of per capita CO_2 emissions on the initial level of per capita emissions for a

[3] CO_2 emissions convergence can, as in the case of income convergence, be roughly divided into three different concepts: *(i)* β convergence; *(ii)* σ convergence and *(iii)* stochastic convergence. These various concepts can in turn be divided into absolute and conditional convergence. In contrast to absolute convergence, conditional convergence assumes the possible differences among countries. β convergence developed by Baumol (1986) occurs when the emissions of a poorer country, with lower initial levels of emission per capita, tend to grow faster than the ones from a rich country and there is a catching-up effect with the more polluting countries. β convergence can be tested by cross-sectional or panel data approach. Notice that this study utilizes cross-sectional β convergence (Pettersson et al. 2014; Panopoulou and Pantelidis, 2009).

cross-section of countries (Pettersson et al. 2014). On the other hand, when the control variables are included, the conditional β convergence is tested.

If β is found negative and statistically significant, it is interpreted as the existence of β convergence (being absolute or conditional depends upon the existence of control variables in the regression) in per capita CO_2 emissions, meaning the CO_2 emissions per capita of different countries converge to the same steady state level regardless of the differences in development gap among countries. Moreover, smaller β implies higher convergence rate (Hao et al. 2015).

Legitimate concerns can be raised about the validity of cross sectional β convergence approach when we review the recent developments in econometric methods such as new estimation techniques (system or difference GMM) for panel data approach, newly developed unit root tests (RALS-LM) or club convergence approach. This is because all these econometric methods can be considered as an alternative to cross sectional β convergence analysis and give more robust empirical results. Even though we are in complete agreement with these concerns, our main aim in this study is to bring how changes in emission accounting system influences empirical results and policy implications up for discussion. Hence, we decided to build our empirical analysis (as a case study) on the research by Strazicich and List (2003) which is the first study analysing conditional convergence in CO_2 emissions.

(ii) Data

The variable selection is one of the most important part of this study. As discussed in the previous section, the empirical literature testing CO_2 emissions convergence so far has commonly employed PBE of CO_2 (Strazicich and List, 2003; Aldy, 2006; Panopoulou and Pantelidis, 2009; Barassi et al. 2011; Yavuz and Yılancı, 2017). This is mainly because it is the officially accepted emissions measurement by the UNFCCC and the data for multiple countries and years are easily available in most datasets. We argue that from a policy perspective, isolating emissions policies from the dynamics of consumption based emissions or ignoring consumption based emissions while making policy implications may lead to failure of these policies. In this respect, we first distinguish between two sides of CO_2 emissions and utilize two primary data: *(i)* annual PBE of CO_2 measured in tonnes per capita (pba); *(ii)* annual CBE of CO_2 measured in tonnes per capita

(cba). The data for pba and cba are taken from Global Carbon Atlas Database[4]. While pba calculates emissions that are generated from the domestic production of goods and services irrespective of whether they are consumed domestically or are exported, cba attributes emissions to the final consumers of goods and services. As discussed above, the difference between two accounting system indicates the net effect of emissions embodied in trade. While positive value of difference indicates net export of emissions, negative value shows net import of emissions.

Secondly, we include a vector of control variables (Z_i) that may be hypothesized to affect long-run emissions rates. They are real GDP per capita (constant 2010 US$) $(gdpper)$, real GDP per capita squared (constant 2010 US$) $(sqgdpper)$, population density (people per square km of land area) (pd) and trade volume per capita (constant 2010 US$) $(xmper)$[5]. The data for $gdpper$, $sqgdpper$, pd, and $xmper$ are extracted from World Bank Development Indicators database. While $gdpper$, $sqgdpper$ and pd are commonly used control variables to test CO_2 emissions convergence in the literature, $xmper$ can be regarded as our contribution to the literature to show the difference between pba and cba.

We follow the suggestion the EKC literature and include real GDP per capita and real GDP per capita squared as the control variables. GDP per capita has a positive relationship with both the pba and cba through different mechanisms. pba increase as GDP per capita increases simply due to every additional production uses more fossil fuels. Therefore, the fossil fuel content of a country's energy mix becomes more important in the in the case of pba. In the case of cba, the mechanism works through the income and consumption relation, such a way that as countries become richer, the households spend more of the production, which results in more in emissions. Hence, the sign of the $gdpper$ is expected to be positive in terms of both CO_2 emissions measures. Next, we include population density. As expressed by Strazicich and List (2003), countries with greater population density will tend to make more efforts to reduce emissions and thus converge to lower emissions rates. Our expectation for population density, therefore, is negative. However, it is important to emphasize that while the effect of population density on emissions rates may be statistically significant and greater (the absolute value) in magnitude in terms of pba, this may not be necessarily true for cba. This is because, the emissions policies to

[4] The Global Carbon Atlas Database can be viewed from http://www.globalcarbonatlas.org/en/CO2-emissions
[5] $xmper$ data is calculated by dividing exports plus imports of goods and services by total population.

reduce GHGs directly target the reduction of pba rather than cba. In addition to standard variables, this study also considers a newly identified control variable in order to examine for the effects on conditional convergence: trade volume per capita. This variable is considered to be more closely related with cba emissions rather than pba. Both the trade volume and patterns of trade are expected to have a significant impact on cba (Liddle, 2018). The gap between embodied emissions in imports and exports might be due to the increasing gap between the trade volume of imports and exports as well as changing trade patterns. If a country experiences a huge trade deficit, where imports exceed their exports, it is more likely that this country will have a higher CBE than PBE. If, on the other hand, this country dominantly exports energy intensive products and imports less energy intensive products in their trade, it is possible to see that the country's CBE are lower than its PBE. According to 'Pollution Heaven Hypothesis', for instance, pollution intensive industries will contract in countries with relatively strong environmental regulation and expand in those where there is no or relatively weak environmental regulations. (Copeland and Taylor, 2013). Such environmental policy differences may serve as an important source of comparative advantages for the latter group of countries. As earlier global climate agreements, particularly Rio Convention and the Kyoto Protocol, did not include all countries in terms of GHG reduction pledges, the issue of carbon leakage has been seen a serious challenge to international climate mitigation programmes. Within this context, level and driving forces of "carbon leakage" issues have been extensively discussed in the literature (Barrett et al., 2013; Böhringer et al., 2017). Due to the concerns regarding carbon leakage may have undermine climate policies, studies focused on cba, as this approach practically identifies embodied emissions on traded products (Peters et al., 2016). We, therefore, believe that including $xmper$ as a control variable will provide us some useful insights to analyse the result of the findings.

This study covers 35 Annex-B countries for the period between 1990 and 2015. The countries are listed in Table 1.[6] In all estimations, all series are in natural logarithm and 2003 is chosen to serve a midpoint in our sample for all control variables.

[6] Due to the issues on completeness of data on cba, we excluded Iceland, Liechtenstein, Luxemburg, Malta and Monaco from the original Annex-B list.

Table 1: Country list

Australia	Estonia	Latvia	Slovak Republic
Austria	Finland	Lithuania	Slovenia
Belgium	France	Netherlands	Spain
Bulgaria	Germany	New Zealand	Sweden
Canada	Greece	Norway	Switzerland
Croatia	Hungary	Poland	Ukraine
Cyprus	Ireland	Portugal	UK
Czech Republic	Italy	Romania	USA
Denmark	Japan	Russian Federation	

Before proceeding to the empirical results, a simple approach to detect convergence or divergence in our sample in terms of both CO_2 emissions measures can be useful. Figure 1 and 2 present a scatter plot of each 35 countries' average CO_2 emissions per capita growth between the period 1990-2015 against its initial value (1990). Both figures reveal a negative relationship between average growth rates and initial values, suggesting CO_2 emissions convergence. However, it is obviously seen that the slope of pba is steeper than the slope of cba indicating speed of absolute convergence is greater in magnitude for pba. Not surprisingly, this may be a consequence of solely taking into account production side of CO_2 emissions while making policy implications. Of course, these figures can be regarded only as a preliminary analysis and do not give any information about the magnitude and statistically significance of the convergence parameter or the effect of control variables on convergence. We now turn to examine the statistical significance of convergence parameter and the effect of control variables on convergence.

Figure 3: Production based CO_2 emissions convergence

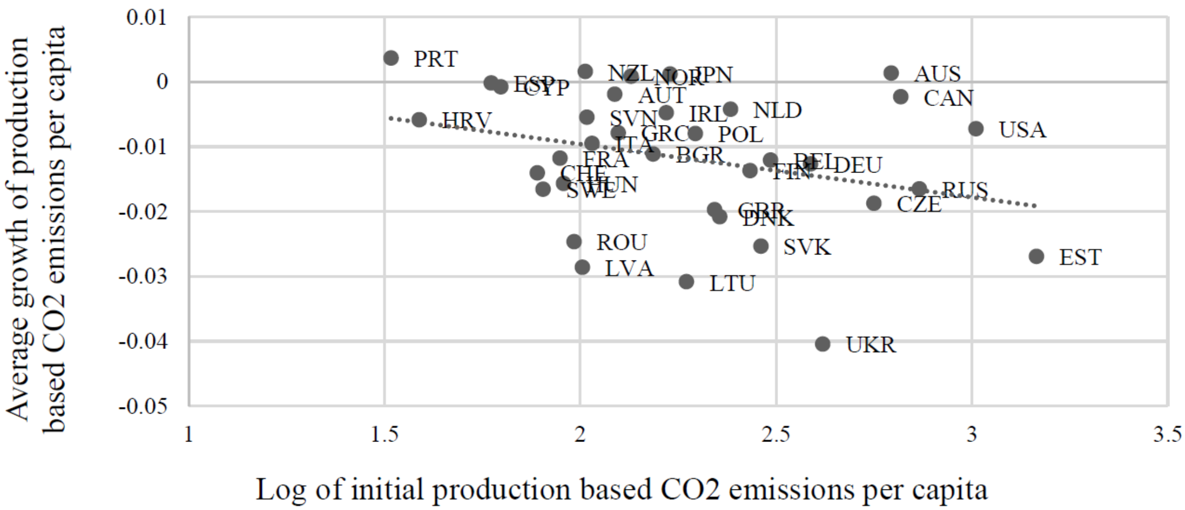
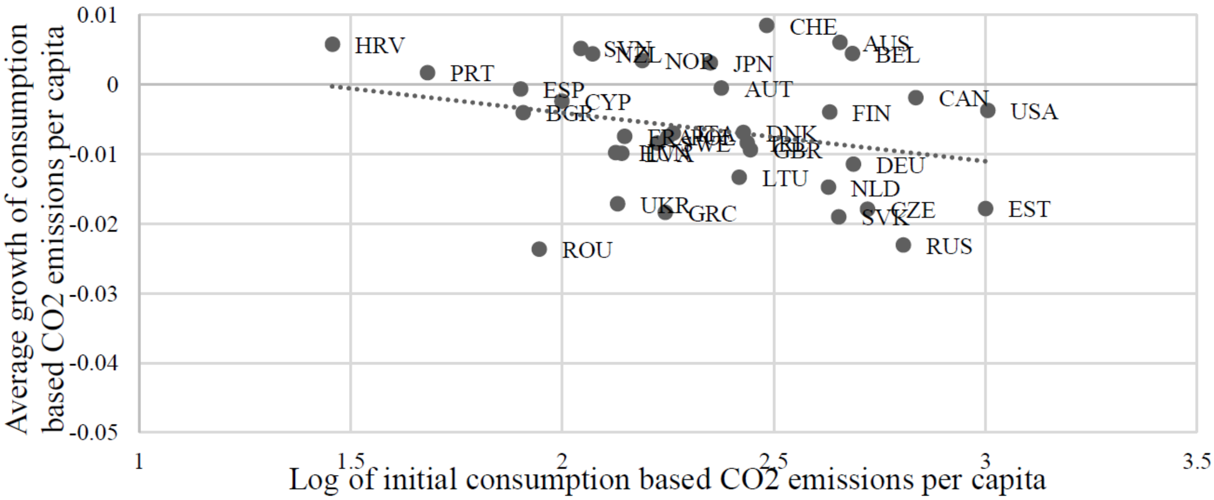


Figure 4: Consumption based CO_2 emissions convergence



(iii) Findings

This study first tests the absolute β convergence, yet we also include a number of control variables into the empirical test to analyse conditional convergence. While doing this, we also try to see the impacts of different combinations of control variables in order to test the robustness of the empirical analysis.

Cross sectional regression test results for 35 Annex-B countries for the period 1990-2015 are summarized in Table 2. While dependent variable is the average growth rate of pba for the upper panel of Table 2, it is the growth rate of cba for the lower panel of Table 2.

The second and third columns give the constant term and the coefficient of convergence parameter (β), respectively. Eqs. (2.1) and (2.7) show the absolute convergence results, while Eqs. (2.2) to (2.6) and (2.8) to (2.12) present conditional convergence results using different control variables. As indicated before, β is expected to be between 0 and -1 as an indication of convergence and the higher absolute value of β, the stronger convergence.

Table 2: Cross-section tests for conditional convergence in per capita production based and consumption based CO_2 emissions among 35 Annex-B countries from 1990 to 2015

Eq.	α	β	$gdpper$	$sqgdpper$	pd	$xmper$
Dependent variable: average growth rate of production based CO_2 emissions per capita						
2.1	0.007	-0.008				
	(0.66)	(-1.82)*				
	$\bar{R}^2$=0.064		F=3.31*		n=35	
2.2	-0.070	-0.007	0.007			
	(-3.67)***	(-2.03)*	(4.46)***			
	$\bar{R}^2$=0.404		F=12.53***		n=35	
2.3	-0.033	-0.007		0.0004		
	(-2.69)**	(-2.05)**		(4.35)***		
	$\bar{R}^2$=0.393		F=12.02***		n=35	
2.4	0.020	-0.010			-0.002	
	(1.45)	(-2.20)**			(-1.39)	
	$\bar{R}^2$=0.089		F=2.67*		n=35	
2.5	-0.040	-0.007				0.005
	(-1.84)	(-1.68)				(2.40)**
	$\bar{R}^2$=0.182		F=4.78**		n=35	
2.6	-0.263	-0.009	0.056	-0.002	-0.001	-0.006
	(-1.60)	(-2.49)**	(1.66)	(-1.28)	(-1.26)	(-1.80)*
	$\bar{R}^2$=0.487		F=7.46***		n=35	
Dependent variable: average growth rate of consumption based CO_2 emissions per capita						
2.7	0.010	-0.007				
	(1.01)	(-1.68)				
	$\bar{R}^2$=0.051		F=2.82*		n=35	
2.8	-0.049	-0.011	0.007			
	(-3.44)***	(-3.45)***	(4.88)***			
	$\bar{R}^2$=0.439		F=14.31		n=35	
2.9	-0.016	-0.011		0.0004		

	(-1.72)*	(-3.47)***		(4.93)***		
	$\bar{R}^2$=0.443		F=14.54***		n=35	
2.10	0.016	-0.008			-0.001	
	(1.35)	(-1.82)*			(-0.91)	
	$\bar{R}^2$=0.046		F=1.81		n=35	
2.11	-0.036	-0.010				0.006
	(-2.44)**	(-2.82)***				(3.73)***
	$\bar{R}^2$=0.318		F=8.92***		n=35	
2.12	0.022	-0.012	-0.007	0.0007	-0.001	0.0003
	(0.16)	(-3.59)***	(-0.23)	(0.45)	(-1.23)	(0.12)
	$\bar{R}^2$=0.420		F=5.92***		n=35	

Note: dependent variable is the average annual growth rate of CO2 emissions in country i. t statistics are shown in parentheses. *, ** and *** denotes significance at 10%, 5% and 1%, respectively.

The third column of Eq. (2.1) and (2.7) shows the results for absolute convergence. While statistically significant β coefficient (-0.008) between 0 and -1 indicates absolute convergence in pba, it is clearly seen that the absolute convergence parameter (-0.007) is negative but statistically insignificant for cba. In addition to this, in accordance with Figure 1 and 2, the speed of convergence in pba is greater than cba (in despite of statistically insignificance of this coefficient). It means that the slope of convergence in pba is getting stepper than cba.

When $gdpper$ is used as a control variable, both convergence parameters reported in third column in Eqs. (2.2) and (2.8) (-0.007 and -0.011) are statistically significant at 10 and 1% levels and the sign of $gdpper$ provides a strong support for our position on our expectations. The fact that $gdpper$ has a positive relationship with both the pba and cba through different mechanisms can be clearly seen in these empirical results. Moreover, while the absolute value of conditional cba convergence parameter increases (from 0.007 to 0.011), the absolute value of conditional pba convergence parameter decreases (from 0.008 to 0.007). Same conclusion appears when $sqgdpper$ is used as a control variable (from 0.007 to 0.011 vs. from 0.008 to 0.007).

Eqs. (2.4) and (2.10) suggest that pd is negative (this is also consistent with our expectations) and but statistically insignificant at conventional levels. The fact that the emissions policies to reduce air pollutants directly target the reduction of pba rather than cba is obvious in the estimate results of Eqs. (2.4) (2.10). This is because while the absolute value of convergence parameter increases the highest point (0.010) for pba, it almost remains same (0.008) (the lowest point) for cba.

When we consider our newly identified control variable ($xmper$) shown in Eqs. (2.5) and (2.11), we can suggest that $xmper$ is statistically significant in both cases (0.005 vs. 0.006), indicating it has a significant effect on convergence in terms of pba and cba. However, in accordance with our expectations, this so-called effect is greater for cba. Moreover, while the convergence parameter for cba (-0.010) is highly significant at 1% level, it is statistically insignificant for pba (-0.007).

(iv) Discussion of the Results

The CO_2 convergence per capita results are compared and assessed accordingly, for the Annex-B countries with pba and cba.

On absolute convergence, our model finds a different pattern, such that while per capita emissions calculated by PBA shows convergence at %10 significance level, the per capita emissions calculated by CBA indicates divergence among the Annex-B countries for the period of 1990-2015. This raises the issue of fairness in the allocation of responsibility between producers and consumers. As argued earlier, an international emissions allocation that is assigned based only on PB principles ignores the fact that those emissions are actually consumed somewhere else through trade. Therefore, finding convergence in per capita emissions among the sample countries based on PBA does not necessarily refer to a fair distribution of emission allocation in global climate agreements. Since our results indicate divergence in per capita consumption emissions, developing countries will be less likely to agree on burden sharing allocation of emission distribution adopted by the Annex-B countries. This will put forward a strong case for developing countries asking for incorporating consumption based principles into climate negotiation talks.

Likewise, by comparing the convergence results, it is possible to have, at least, some idea on the relationship between income and environmental pressure, specifically on decoupling issues. As our CBE analysis does not find absolute convergence among the Annex–B countries, similar to Mir and Storm (2016) argument, this result might support the claim that there is no convincing decoupling taking place between the income and emissions for the sample period. While acknowledging the recent improvements in emissions reduction in the developed regions, the observed PBE reductions achieved by the Annex-B countries could, therefore, partially be due to outsourcing these emissions to non-binding developing countries.

Model results with control variables provide some important implications on conditional convergence, which also support for the arguments of the need for separation of the convergence data based on PBA and CBA.

$gdpper$ has positively correlated and statistically significant for both pba and cba. It is reasonable to expect such outcome for both cases. Moreover, similar to Fan et al. (2016) findings, the impact of $gdpper$ on convergence in cba has been more stronger. This is also what one would expect as CBA data includes both domestically consumed and imported emissions. Since economic theory suggests that imports are positively and closely corraleted with the level of domestic income, when countries get richer, this will lead to increases in imports and consequently increases in imported emissions. PBE, however, include exported emissions alongside domestically consumed and as economic theory suggests that exports are dependent on the partner countries income rather than the domestic income. As a result, impacts of $gdpper$ will be limited on the pba only through domestic consumption.

In the case of pd, we have seen a reverse outcome compared to $gdpper$, such that including the pd had more influence on conditional beta convergence for the pba compared to cba. As discussed above, pd is more influenced with PB policies and therefore it would have more impact on pba and less on cba.

As we highlighted earlier, main difference between the PBA and CBA systems is to distinguish the embodied emissions in trade. The control variable of $xmper$ is particularly introduced to see the role of the foreign trade in CO_2 emissions growth. When the $xmper$ is included in model, we see that it has no significant impact on pba as the beta sign is statistically insignificant even at the %10 level. The result with the cba, however, finds that the $xmper$ has significant impact on consumption per capita emissions growth and beta is statistically significant even at the %1 level. Besides, the magnitude of the beta coefficient becomes much stronger. Similar to Liddle (2018) findings, this outcome supports our argument that foreign trade is an important factor in affecting the growth of CO_2 emissions and therefore comprehensive trade related policies should be designed to tackle to curb the emissions.

Finally, when the model includes all control variables, both data sets result in improving the beta convergence, however, the impact on cba is even stronger. Another important finding is that the PBE data provides some support for the existence of EKC hypothesis, yet the CBE data does not support the EKC as the signs of $gdpper$ and $sqgdpper$ are opposite the expectations and statistically insignificant.

5. Conclusion

Emission and economic growth relationship has been analysed extensively by many studies. Several empirical analyses are applied on these issues and it is important to notice that the analyses are based on emissions data provided by PBA. This study argues that many of these analyses could be misleading or incomplete only relying on data provided by PBA as it ignores trade perspective.

Today, we live in a world in which economic production process and supply chains are international and global trade of goods and services from production sites in one country to final consumers in another is very common in this globalized network of production and consumption, who should be held accountable for reducing associated ghg emissions. Studies indicate that emission reductions achieved by the Annex-B countries during First Kyoto Period were offset by net emission transfers from Non-Annex B to Annex B countries. This emphasizes the importance of considering alternative emission calculations and new policy perspectives.

This study, therefore, suggests that CBE accounting should be considered as an important tool in CO_2 emission analysis. CBE particularly address emissions embodied in trade, that is not included in traditional production based national emissions inventories. With the CBA system, it is possible to identify whether developed countries truly reducing their GHG emissions with their own domestically implemented policies and measure or do they simply outsource some of their emissions to unregulated developing countries. CBE, as an alternative to PBE, could provide significant advantages to policymakers both in terms of presenting valuable tools for understanding CO_2 emission patterns in detail and to develop target based policies and measures to address emissions originating from outside country (Afionis et al., 2017).

This study particularly discusses and analyses the convergence in CO2 emissions with a focus on how the outcome differs when CBE accounting taken into consideration. As almost all literature on environmental convergence employs data based on standard production perspective, it can be argued that such assessment could be incomplete and needs further insight with the CBE. Convergence analysis using per capita CBE will provide better information and make more sense in terms of analysing climate change and economic growth relationship issues, such as decoupling and the EKC by linking emission leakage concerns.

The literature on CO_2 emission convergence assume that, with the CBDR principle of the UNFCCC, countries with low initial per capita emissions will be allowed to increase and catch up those countries, whose emissions are initially higher. As a result there will be either an absolute convergence in per capita emissions among the countries in the long run, or countries will experience a conditional convergence, which means those heterogeneous country groups will target to reach a different steady states in a specified time horizon (Barassi et al; 2017).

The empirical part of this study tests beta convergence of CO_2 per capita measured both by PB and CB accounting system. It is argued that convergence results may be the same or considerably differ when the accounting system is distinguished. By doing so, a number of conclusions and policy implications can be drawn depending on the results obtained from different accounting systems.

PBE model results show the existence of a negative and statistically significant relationship between initial levels of CO_2 emissions per capita and subsequent growth rates. When convergence in per capita consumption emissions is tested, we find no absolute convergence for the Annex-B countries. Inclusion of some of the control variables, however, makes the convergence results more robust for the CBE analysis as the beta becomes more significant and stronger.

Since our results indicate divergence in per capita consumption emissions, in contrary to convergence findings for the production based CO_2 per capita, this would imply that developing countries will be less likely to agree on burden sharing allocation of emission distribution adopted by the Annex-B countries. The PBE results indicate that there is existence of EKC relationship as emissions per capita increase with the GDP per capita but decrease with the $sqgdpper$. Yet, we see no evidence of EKC when we run the model with consumption based emissions per capita as the signs are in opposite direction and statistically insignificant. From our convergence analysis and EKC assumptions, it is fair to argue that policymakers should not confidently assume that economic growth will also bring environmental improvement in coming years. Even though we might see some improvements in energy efficiency and deployment of renewable energy, it is important to develop further mitigation policies and measures to tackle CO_2 emissions. These policies should particularly focus on consumption as it is an important driver of emissions that needs to be more specifically targeted. The findings of the study also suggests that at least some part of the observed decoupling of economic growth and production based CO_2 emissions among the Annex-B countries are indeed due to the leakages. Without policy attention to this sort of interregional carbon leakage, developing countries will struggle to meet their emissions targets that are committed at the Paris Agreement.

In order to reduce CBE, countries should adopt new and innovative tools to target how to change consumer behavior, by providing knowledge and incentives to switch to smoother low carbon society. New policies and measures should also address to decrease embodied emissions in traded products originating from other countries. Recent studies discuss a number of CB policy instruments that may help improve the economic well-being and environmental effectiveness of unilateral climate policies (Peters et al., 2016).

Finally, it is also important to notice that CBA should not be considered as a substitute, instead it should be considered as a complementary to the PBA system. With the CBA, it is possible to identify new policy interventions and increase the potential to break down barriers that exist between developed and developing countries in international climate policy (Scott and Barrett, 2015).

Since this study argues that many existing studies on convergence analysis are misleading as they use only PBE data and challenges the results as they partially capture the whole picture of the theoretical framework of the CO_2 emissions and economic growth nexus, there are many dimensions of future studies on convergence, which needs to be explored. In this regard, we suggest future studies analysing environmental convergence by using different MRIO databases (both PBA and CBA data) with more heterogeneous country groupings and also at sectoral level within the country, with different convergence indicators (such as emissions per gdp, energy per GDP) and certainly with different convergence techniques (such as conditional convergence, sigma convergence and club convergence).

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