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Does corporate carbon performance converge in the global market? Evidence from a distribution dynamic approach

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Abstract: Converging corporate carbon performance (CCP) to a higher level is necessary to achieve the global goal of controlling temperature rise. However, it remains uncertain whether all international firms endeavour to improve CCP. Using a panel of 19,913 public companies from 76 countries during the 2010-2019 period and two visual tools of the distribution dynamics approach, we conduct a nascent analysis of transitional dynamics and the long-run evolution of CCP. We find that regardless of investigated period (before and after Paris Agreement) and regional location, most firms converge towards the highest CCP of 10, thereby improving carbon performance over time. After Paris Agreement, the convergence to the top CCP is more significant, whereas more companies cluster around the mediocre CCP (a value of 6.7), thus evidencing an increased heterogeneity in convergence paths. Firms from East Asia & Pacific and the North American regions drive such heightened heterogeneity. Specifically, enterprises from East Asia & Pacific show the least convergence towards the highest CCP, probably because more manufacturing firms in the region primarily rely on fossil fuels and face loose environmental regulations. Therefore, further improving CCP may require substantial investments in equipment upgrades and would result in significantly higher costs. For North America, the results can be associated with Donald Trump's policy towards climate change and bid to withdraw from the Paris Agreement, reflecting firms taking a Republican stand, most likely diverging to mediocre CCP and experiencing a decline in future carbon management. The observed convergence towards the highest CCP is nearly twice as significant among firms from OECD than non-OECD countries, which aligns with global enterprises outsourcing emissions to developing countries. The study reveals the pattern of strong convergence to the highest CCP in the global firms as evidence of collective efforts in the transition to net zero. However, divergence and increased heterogeneity may occur in some regions due to politics, industrial structure and regulations.

Keywords: Corporate carbon performance; OECD; Paris Agreement; Distribution dynamics approach; Convergence club

1. Introduction

In 2015, 196 countries signed the Paris Climate Agreement to control the long-term temperature rise associated with emissions of greenhouse gases (hereafter GHG), particularly carbon dioxide (Liu et al., 2023). If all signatory countries achieved pledged climate actions, known as Nationally Determined Contributions, global carbon emissions would be reduced (Liu et al., 2020). Furthermore, if all parties exerted efforts to improve environmental performance, the cross-country inequalities would decrease. However, the pledged climate goals seem unachievable with the implementation gap in many countries (Roelfsema et al., 2020) and carbon leakage. Furthermore, it is unclear whether corporations in the global market can collectively reduce emissions and converge to a high level of carbon performance.

Previous studies explore the cross-country convergence in carbon emissions but yield mixed results. One strand of literature focuses on global paths of convergence. For example, Ezcurra (2007) employs Quah (1993) 's distribution dynamics approach (hereafter DDA) and evidences the convergence towards the average CO2 emissions among 140 countries. On the contrary, Criado and Grether (2011) employ the Markov analysis technique for the panel of 166 countries, showing an increased divergence in the long-run per capita carbon emissions. Another strand of the literature examines carbon emissions of developed vis-à-vis developing countries but delivers mixed and contradictory findings. For example, Nguyen Van (2005) and Aldy (2006) use the DDA and show a long-run convergence only across 26 and 23 developed economies in the panel of 100 and 88 countries, respectively. However, Westerlund and Basher (2008) document the convergent path for developing and industrialised countries. According to Brännlund and Karimu (2018), the beta convergence is slower in high- than in low-income countries. On the contrary, Li et al. (2020) report significantly faster convergence in CO2 emissions across developed vis-à-vis developing countries. Notwithstanding, others document a lack of convergence among industrialised OECD (Barassi et al., 2008) and G7 countries (El-Montasser et al., 2015). Furthermore, some studies suggest that countries in the same region may exhibit environmental convergence due to regional cooperation (Han et al., 2018), while neighbouring economies could affect carbon emissions (Rios and Gianmoena, 2018).

While ample research investigates emissions at the country level, studies focusing on firm-level CO2 emissions and performance are relatively rare and concentrate mainly on the effects of corporate governance. For example, Moussa et al. (2020) and Haque and Ntim (2022) document the positive impact of corporate board environmental orientation and corporate sustainability initiatives on enterprises' carbon performance in the US and the EU, respectively. Even fewer studies explore the patterns of corporate emissions from a global perspective. Azar et al. (2021) evidence a significantly negative effect of institutional investors on public companies' CO2 emissions. Cheng et al. (2023) analyse the dispersion (Theil index) of country-level corporate carbon performance (hereafter CCP) in a panel of firms from 64 countries. The authors find a more significant reduction in the dispersion post-Paris Climate Accords across enterprises from developed compared to developing countries. However, to our knowledge, there is no research on the convergence of CCP in the global markets, which constitutes a gap in the literature.

The above research gap is puzzling given that according to a report by Generation Investment Management (2021), publicly listed firms emit around 40 per cent of total carbon emissions worldwide. Consequently, the improvement of CCP is one of the critical conditions necessary to achieve the target of limiting the temperature rise as per the Paris Agreement (Cheng et al., 2023). However, this would require global enterprises to restrict carbon emissions significantly and converge their environmental performance towards a higher (greener) level (MSCI, 2021). Notwithstanding, the convergence of CCP (to a greener level) remains uncertain for at least three reasons. First, firms in different countries confront diverse environmental pressures from stakeholders and regulators. For instance, enterprises in civil-law countries are more concerned about stakeholders (Liang and Renneboog, 2017) and thus may exert more effort to reduce carbon emissions. However, corporations in common-law countries weigh shareholders' value more and may resist taking costly actions to improve carbon performance. Second, the costs of enhancing carbon management could be different in companies from various countries due to e.g., diverse industrial structures (Poumanyvong and Kaneko, 2010), urbanisation (Wojewodzki et al., 2023), the reliance on fossil fuels (Welsby et al., 2021) and R&D advancements (Milindi and Inglesi-Lotz, 2022). Third, corporations operating in advanced economies with stricter green regulations may *outsource* carbon emissions to upstream and downstream enterprises (from the global supply chain) operating in locations with lenient environmental regulations (Singhania and Saini, 2023). Consequently, these enterprises may improve carbon performance at the expense of upstream and downstream firms. Therefore, it is unclear whether the carbon performance of publicly listed companies in the global market would converge to a higher standard.

Given the above background, unveiling the current and future convergence-divergence path of global enterprises' CCP bridges the research gap and is necessary to design and execute efficient environmental policies to achieve global climate goals. Thus, our study has three primary objectives. First, to explore the convergence-divergence pattern of carbon performance in global enterprises. Specifically, we investigate whether the Paris Agreement accelerated the environmental convergence since many countries have pledged to reduce GHG emissions and achieve carbon neutrality by 2050 (UNFCCC, 2023). Second, to examine the convergence of CCP within and across regions to reveal whether firms in some regions lag in the overall improvements in emissions reduction. Third, to document and compare the convergence paths of CCP within and across the groups of OECD and non-OECD countries.

A carbon emissions score from a leading ESG rating agency, MSCI, measures CCP. The score ranges from zero to 10 and captures a firm's vulnerability to carbon risk and its capacity to handle it, such that the higher the score, the better the carbon performance (MSCI, 2023). We use a global sample of 19,913 publicly listed firms from 76 countries and 82,736 firm-year observations from 2010 to 2019. We employ two graphical tools of DDA to reveal (1) a complete forecast of bi-dimensional distribution in the long-run steady-state equilibrium and (2) the movements of enterprises with different CCPs within the distribution.

This study aims to contribute to the existing literature in the following aspects. First, to our knowledge, this is the nascent empirical exploration of convergence in global carbon performance at the firm level, thereby bridging the above-outlined gap in the extant studies focusing on country-level emissions. Moreover, based on a uniquely comprehensive firm-level dataset and ergodic distribution tool of the DDA, we provide initial evidence on the long-term evolution (e.g., the emergence of convergence clubs) in global CCP. Traditional econometrics approaches cannot provide such information (e.g., Maasoumi et al., 2007) and only yield a single output value. Furthermore, popular parametric methods of sigma and beta convergence can be deceptive and inadequate as convergence tests (e.g., Juessen, 2009). Additionally, we expand the existing body of knowledge using Mobility Probability Plot (hereafter MPP) to reveal the differences in transitional dynamics of CCP (1) before and after the Paris Climate Accords, (2) between OECD and non-OECD countries and (3) across four major regions. The MPP tool also identifies the policy priority list, i.e., firms with the most significant probability of deteriorating CCP in the coming years. Finally, we deliver fresh insights and policy implications to governments and stakeholders concerned about global climate targets and corporate carbon management.

The rest of this study is structured in the following order. Section 2 outlines the dataset and the research methods employed. Section 3 presents and discusses the results, whilst Section 4 concludes the paper.

2. Methodology

2.1 Sample and data sources

We obtain the annual firm-level observations of carbon emissions scores (our CCP variable) from the ESG Intangible Value Assessment (hereafter IVA) database by MSCI. This dataset offers a general ESG score, individual scores for the environment (E), social (S) and governance (G) pillars, as well as separate scores corresponding to different "Key Issues" under each of the three pillars (MSCI, 2023). Carbon emissions are a "Key Issue" within the E-pillar for public companies. Specifically, using various sources of data (e.g., the firm's annual reports, sustainability disclosures, public databases and media), MSCI quantifies enterprises' vulnerability associated with the risk of carbon emissions and the firm's ability to handle it. The above data is then merged into the carbon emissions score such that "a higher level of exposure requires a higher level of demonstrated management capability to achieve the same overall Key Issue Score" (MSCI, 2023).

Two primary benefits of using the MSCI IVA database are as follows. First, MSCI is the biggest supplier of ESG data for publicly listed companies in global markets (Cheng et al., 2023). Furthermore, since their inception, MSCI's carbon emissions scores range consistently from zero (the worst) to ten (the best), enabling the comparison of CCP over time and across countries. Thus, the data fits with our research objective to compare the carbon performance of enterprises in the global market and their evolution (convergence versus divergence) over time. After removing observations with missing scores, the final sample contains 19,913 listed firms and 82,736 firm-year observations from 76 countries. The sample covers the period from 2010 to 2019.

Table 1 details the number of companies with non-missing annual CCP. Consistently with the expanding coverage of the MSCI IVA database, the number of corporations in the sample has increased significantly from 1,866 in 2010 to 14,982 in 2019. The global sample is divided into two subsamples: OECD and non-OECD countries. Table 1 shows more companies headquartered in OECD member countries, especially in the early years. Specifically, there were 180 (1,706) firms from non-OECD (OECD) economies in 2010, whilst the numbers increased substantially and somewhat converged to 4,572 (10,410) in 2019.

[Insert Table 1 here]

We divide the overall sample following the World Bank's classification into four regional subsamples: (1) East Asia & Pacific, (2) Europe & Central Asia, (3) North America and (4) Other. The fourth region (Other) includes firms located in countries from Latin America & Caribbean, the Middle East & North Africa, South Asia, and Sub-Saharan Africa regions. The number of firms in North America is the most extensive due to comprehensive MSCI data coverage of the US enterprises. On the contrary, we can observe that the number of firms in the Other region is consistently the smallest, particularly in the early years. Table 2 reports the average annual CCPs in the final sample and subsamples.

[Insert Table 2 here]

We can observe that the average annual CCP in the global sample increased from 4.9 in 2010 to 7.36 in 2019. Furthermore, the average score reached the maximum value of 7.44 in 2017 but decreased slightly in 2018 and 2019. Overall, the CCP improved over time in all subsamples, whilst the average scores are generally higher for firms in the OECD vis-à-vis the non-OECD countries, except for 2016 and 2017. However, the average CCP in the non-OECD economies caught up with the CCP in the OECD members over time.

Across regions, enterprises from Europe & Central Asia consistently outperformed firms from the other regions. For instance, only companies from the Europe & Central Asia region achieved an average CCP value above 8 in five of the sampled years (2013-2014 and 2017-2019). 5,001 firms from Europe & Central Asia are located overwhelmingly in the European Economic Area (4,704). Therefore, the results can be associated with evidence that the EU is the vanguard of promoting and enforcing environmentally oriented technologies and laws[1]. On the contrary, firms in North America consistently scored the worst among the regions.

[1] To mention a few of the EU's environmental initiatives such as the Climate and Energy Package (European Commission, 2022a), the Climate and Energy Framework (European Commission, 2022b), the 2050 Long-term Strategy (European Commission, 2022c), or the European Green Deal (European Commission, 2022d).

2.2 Analytical framework

This study employs the distribution dynamics approach (hereafter DDA) first proposed by Quah (1993) to overcome the problems associated with using econometrics in convergence studies. Specifically, we use the DDA's stochastic kernel type, which successfully circumvents the problem of arbitrary demarcation of the state, typically associated with the Markov transition matrix approach (Cheong and Wu, 2018). We present the DDA bivariate kernel estimator in equation (1).

$$\hat{f}(x,y) = \frac{1}{nm_1m_2}\sum_{i=1}^{n} K(\frac{x-X_{i,t}}{m_1},\frac{y-X_{i,t+1}}{m_2}) \quad (1)$$

x represents the CCP in year t, y represents the CCP in the coming year $t+1$, $X_{i,t}$ is an observed CCP score in year t, and $X_{i,t+1}$ is the observed CCP score in the coming year $t+1$. The term n stands for the number of observations, m_1 and m_2 are the bandwidths computed according to the suggestions offered by Silverman (1986), and K is the normal density function. To consider potentially scant observations, we use an adaptive kernel with flexible bandwidth (Silverman, 1986). Assuming the evolution does not change over time and is of the first order, the distribution in period $t+\lambda$ only depends on t but not on past distributions (see Maasoumi et al., 2007). Therefore, the following function illustrates the relationship between the distributions of CCP in periods t and $t+\lambda$.

$$f_{t+\lambda}(z) = \int_0^\infty g_\lambda(z|x) f_t(x)dx \quad (2)$$

Similar to e.g., Lee et al. (2021), the above formula shows how one can compute $f_{t+\lambda}(z)$, which represents the λ-period-forward density function of z conditional on x. The calculation is the product of $f_t(x)$, which stands for the kernel density function, and also, $g_\lambda(z|x)$, which represents the probability kernel function necessary to compute the distribution of the CCP from period t to $t+\lambda$. In the next step, we can illustrate the ergodic density function in equation (3).

$$f_\infty(z) = \int_0^\infty g_\lambda(z|x) f_\infty(x)dx \quad (3)$$

$f_\infty(z)$ is the ergodic density function characterising the distribution of the CCP in the long-run steady-state equilibrium when λ is infinite. Traditional display tools of the stochastic kernel approach, such as the contour map or the three-dimensional plot, cannot show the mobility probabilities of the variable cross-sections and different periods in one graph. To address this problem, Cheong and Wu (2018) developed the mobility probability plot (hereafter MPP) by calculating $p(x)$, i.e., the net upward mobility probability as in equation (4).

$$p(x) = \int_x^\infty g_\lambda(z|x)dz - \int_0^x g_\lambda(z|x)dz \quad (4)$$

The MPP illustrates the net upward mobility probability (vertical axis) against the CCP (horizontal axis) on the graph. It is conveniently expressed in percentages ranging from -100 to 100, making interpreting results easy and user-friendly (Williams et al., 2022). Specifically, a positive (negative) MPP implies that the firm's CCP has a net probability of moving up (down) within the distribution in the coming years. Because of its advantages, MPP has been used in various fields of empirical research investigating e.g., Chinese households' carbon emissions (Zhang et al., 2020), income inequality (Shen et al., 2021), or housing affordability (Liu et al., 2022).

3. Results and discussions

3.1 CCP transitional dynamics and long-run evolution in the global sample

The ergodic distribution in Figure 1 represents the long-run steady-state equilibrium[2] of CCP based on an unbalanced global sample of 19,913 publicly listed companies from 76 countries. We can observe a heavily left-skewed distribution with a steeply-sloped tall, prominent peak centred around the highest CCP value of 10. This result means that most firms will converge towards the highest (optimal) CCP in the long run, thus improving or maintaining their carbon performance. Moreover, Figure 1 illustrates the distribution with a skinny left tail up to the CCP value of 4, suggesting that only a few firms (outliers) will have poor CCP (ranging from 0 to 4) in the long run. The results could be associated with a fast-growing number of corporations publicly setting ambitious "science-based" targets for GHG emissions following the goals of the Paris Agreement (see SBTi, 2023).

[Insert Figure 1 here]

Figure 1 also shows that the distribution is trimodal and has two minor peaks: the relatively more (less) pronounced around the CCP value of 6.7 (8.1). This finding indicates the emergence of three convergence clubs, with most firms converging towards the top CCP, whereas two small groups of firms follow a divergent path and cluster around the CCP values of 6.7 and 8.1. The result is consistent with Rios and Gianmoena (2018), who find evidence of three clubs in country-level per capita CO2 emissions based on a panel of 141 countries. Overall, Figure 1 presents an optimistic outlook from the perspective of carbon performance improvement and convergence, suggesting collective efforts of global enterprises in transition to net zero.

Figure 2 shows precise probabilities of firms' CCP moving up (MPP above the horizontal axis) and down (MPP below the horizontal axis) within the distribution in future years. This piece of information, in turn, can help the decision-makers to identify the corporates with the highest tendency to deteriorate in terms of carbon performance. Given limited resources, these enterprises can then be placed into the so-called *policy priority list*, monitored, and, if necessary, subjected to tailor-made pragmatic policies to reverse the negative forecast changes in CCP.

Figure 2 illustrates that the MPP lies below the horizontal axis only for the small range of CCP values from 6.7 to 7.2. This finding suggests that only global enterprises with such a range of CCP will tend to move down in the distribution in the future, thus meriting particular consideration from

[2] This is under the assumption of no changes in the transitional dynamics (Juessen, 2009).

the policymakers and placement on the *policy priority list*. Furthermore, the results in Figure 2 indicate that the decision-makers should be concerned primarily with (and monitor) firms whose CCP oscillates around 6.85 because of the highest 20 per cent probability (corresponding to the MPP value of 20 as per the vertical axis) of a future reduction in their carbon performance.

[Insert Figure 2 here]

3.2 CCP transitional dynamics and long-run evolution before and after Paris Agreement

In Figure 3, we superimpose the ergodic distributions based on the 2010-2015 and the 2016-2019 periods, i.e., before and after the signing of the Paris Climat Accords. We can observe that regardless of the period, most global corporations converge toward the highest CCP in the long run. However, the major peak of the pre (post) Paris Accords distribution is significantly shorter (taller). This finding indicates that the global transition towards the top CCP level became more significant after the Paris Agreement. In other words, Figure 3 implies that global enterprises collectively increased their efforts to upgrade carbon performance after the Paris Accords. Such findings are consistent with Cheng et al. (2023), who find a significant reduction in the dispersion of CPP post-Paris Agreement. Moreover, the results align with the evidence that during the 2015-2019 period, the number of firms with CO2 emissions targets increased tenfold compared to the 2000-2014 period (Bjørn et al., 2021).

[Insert Figure 3 here]

Figure 3 further illustrates that the pre- and post-Paris Agreement distribution is bi- and tri-modal. Specifically, we can observe that the peak centred around the CCP value of 6.7 (8.1) is more pronounced (emerges) post-Paris Agreement. Therefore, the results highlight more heterogeneous convergence paths after the Paris Climate Accords, i.e., more companies are inclined to transition towards the mediocre CCP of 6.7, while a small group of firms is taking a new (divergent) path towards a CCP value of 8.1. From the global climate goals perspective, the forecast increased divergence in CCP is worrying because it might jeopardise Paris Agreement targets. Furthermore, these results conflict with the reduced dispersion in CCP reported by Cheng et al. (2023).

Figure 4 displays the MPP for the two subperiods mentioned above. A small section of the MPP (CCP values from 6.7 to 7.2) for the post-Paris Accords period is underneath the horizontal axis. This finding means that in the wake of the Paris Agreement, firms with CCPs within this range of values developed a propensity to decrease their carbon performance in the coming years. Such developments, in turn, translate into an increased global divergence, potentially hindering the prospects of meeting global climate goals. Thus, in terms of reduction and convergence in carbon emissions, the identified companies warrant a place on the *policy priority list*. In particular, enterprises with CCP values around 6.85 and the most significant 28 per cent probability of moving downward in the distribution (the MPP value of 28 on the vertical axis) deserve a high rank in the *policy priority list*. Summing up, alarming evidence of more significant heterogeneity (Figure 3) and increased divergence (Figure 4) calls for further analysis to identify its sources better. Accordingly, in the next part of this section, we investigate the transitional dynamics of CCP across the four regions.

[Insert Figure 4 here]

3.3 CCP transitional dynamics and long-run evolution within and across different regions

Han et al. (2018) argue that regional cooperation is associated with environmental convergence across countries, while Rios and Gianmoena (2018) state that the neighboring countries influence each other's CO2 emissions. However, to our knowledge, we are the first to examine long-run convergence and distribution dynamics of CCP from a regional lens. Accordingly, Figure 5 shows four ergodic distributions representing long-run steady-state equilibria of CCP in four regions: East Asia & Pacific, North America, Europe & Central Asia and Other [3]. The results indicate inter-regional similarities associated with globalisation and internationally pursued policies to improve carbon management. For instance, all four distributions have a long thin left tail and are heavily left-skewed with a major peak centred around the highest CCP value of 10. Moreover, distributions in Figure 5 have an additional minor peak around the CCP value of 6.7. Thus, in the long run, regardless of the region, we can expect the two different convergence paths with many (some) enterprises converging toward the best (mediocre) CCP.

[Insert Figure 5 here]

Notwithstanding, Figure 5 also underlines significant differences among regional distributions. First, varying heights of the major peaks suggest that cross-regional long-run transitions towards the highest CCP will be the most (least) notable for the enterprises headquartered in Europe & Central Asia (East Asia & Pacific) region. On the one hand, stellar performance in carbon management across firms from Europe & Central Asia correlates with the EU's fixation on global warming and carbon neutrality through many policies promoting or enforcing green energy whilst taxing carbon-intensive technologies and fossil fuels. On the other hand, the same strict environmental guidelines are behind regulatory arbitrage; European corporations *outsource* CO2 emissions to upstream and downstream enterprises in developing countries with lenient environmental regulation (e.g., Singhania and Saini, 2023). Notably, 37 per cent of the East Asia & Pacific sample is from China and developing ASEAN countries (Indonesia, Malaysia, Philippines, Thailand and Vietnam) which are the popular location of many upstream and downstream enterprises along the global supply chains. Consequently, carbon *outsourcing* might be the significant factor behind the relatively poorest CCP observed in the East Asia & Pacific distribution.

[3] In the Other region, we include firms headquartered in the following parts of the world: Latin America & Caribbean, the Middle East & North Africa, South Asia, and Sub-Saharan Africa.

The results in Figure 5 also show that for the range of CCP values from 5.5 to 9.5, the East Asia & Pacific distribution is significantly thicker than other distributions and has an additional minor peak around the CCP value of 8.1. Summing up, the presented results suggest the most considerable (significant) divergence (heterogeneity) in the long-run transition path of CCP in East Asia & Pacific. The results can be associated with greater financial and technological barriers faced by the manufacturing entities trying to improve their CCP[4]. Furthermore, the findings are consistent with the evidence of *outsourcing* corporate emissions from high-income to developing countries, known as carbon leakage (King and van den Bergh, 2021).

Moreover, Figure 5 indicates that the minor peak centred around the mediocre CCP value of 6.7 is significantly more evident for the distribution corresponding to the North American sample, of which over 87 per cent of enterprises have headquarters in the US[5]. This observation implies that, compared to other regions, more firms from North America congregate around a mediocre CCP value of 6.7. We can think of two culprits behind the above result. First, from the start of his presidency in January 2017, Donald Trump officially triggered the withdrawal of the US from the Paris Agreement, and this decision was suspected to negatively affect the likelihood of achieving global climate targets (e.g., King and van den Bergh, 2021). Furthermore, President Trump pivoted away from his predecessor's (Barack Obama) policies of promoting clean, renewable energy sources and instead favoured fossil fuels. Given the above, American enterprises under Trump's presidency faced higher costs and lower regulatory pressure associated with environmental efforts. Thus, some firms become more inclined to congregate around a less costly but socially tolerable mediocre CCP value of 6.7. Second, all three countries from the North American sample have common law systems in which public companies emphasise maximising the shareholders' value, i.e., are less inclined (than firms in the civil law countries) to bear additional costs of improving their CCP (e.g., Liang and Renneboog, 2017).

Figure 6 shows that the MPP for Europe & Central Asia region is above the horizontal axis (the remaining three plots) for the full range (most) of CCP values. This finding indicates that only in Europe & Central Asia region, all sampled enterprises display varying proclivities to improve their CO2 performance in years to come. Furthermore, most of the firms from this region have a higher probability of a future increase in carbon management compared to firms with the same CCP values but headquartered in the other three regions. Therefore, we could expect (assuming no changes in transitional dynamics) that public companies in Europe & Central Asia will experience the most considerable upgrading in their aggregate CCP.

[Insert Figure 6 here]

[4] Developing countries tend to be less services-oriented, technologically less advanced (Milindi and Inglesi-Lotz, 2022), more reliant on fossil fuels (e.g., Welsby et al., 2021) and have loose and/or poorly enforceable environmental regulations (e.g., Singhania and Saini, 2023).
[5] The North America Region comprises of 6,117, 780 and 104 firms from the US, Canada and Bermuda, respectively.

Much grimmer findings pertain to the MPP for the North American region, which plots significantly below the other three MPPs at the lowest range of CCP (from zero to 3.2). This observation means that the worst performers (enterprises with CCP ranging from zero to 3.2) headquartered in North America are also the least likely to improve in the following years. On top of that, the North American corporations with mediocre CCP values from 6.7 to 7.2 (see the section of North American MPP below the horizontal axis) merit a top spot in the *policy priority list* due to the most significant probabilities (up to 39 per cent) of a future decline in CCP. Summing up, Figures 5 and 6 deliver novel evidence suggesting that Trump's presidency could be a significant factor behind US corporations' mediocre carbon performance, thereby jeopardising global climate goals (e.g., King and van den Bergh, 2021). The same argument explains a highly similar and more pronounced peak around the CCP value of 6.7 (firms with CCP ranging from 6.7 to 7.2 marked by negative MPP) observed in Figure 3 (4). On a positive note, results might suggest that the EU's strict carbon policies and relentless environmental efforts yield tangible beneficial effects: the largest aggregate improvement in CCP and the most significant convergence towards the top performance.

3.4 CCP transitional dynamics and long-run evolution across OECD versus non-OECD countries

Figure 7 presents the CCP's ergodic distributions of firms headquartered in the OECD versus non-OECD economies. Due to the composition of samples, we refer to the OECD (non-OECD) countries as developed (developing)[6]. Both distributions are virtually identical over the low range of CCP values (from zero to 5.5), heavily left-skewed with a tall, thin prominent peak centred around the top CCP. Such similarities suggest that regardless of OECD membership and economic development, most firms are on the path towards the highest CCP whilst coexisting with outliers (firms with poor or mediocre CCP) in the long run. The results are inconsistent with e.g., Ahmed et al. (2017), who evidence convergence in per capita carbon emissions among 38 (mainly high-income OECD) countries, whereas a divergence across 124 (primarily developing) countries.

[Insert Figure 7 here]

Notwithstanding, Figure 7 also reveals two stark differences between the distributions. First, we can observe one (two) minor peak(s) in the OECD (non-OECD) distribution occurring around the value of 6.7[7] (6.7 and 8.1), thereby suggesting the emergence of two (three) convergence clubs in the long run. Such findings are broadly similar to e.g., Camarero et al. (2013), who document that the carbon emissions intensity in 22 out of 24 OECD countries cluster in four clubs. Second, the major peak in the OECD distribution is almost twice as high as in the non-OECD distribution. This disparity, in turn, translates into a considerably less significant and more heterogeneous

[6] Except for 99 and 152 firms from Chile and Mexico, the OECD sample consists of 14,293 corporations from developed economies. As for the non-OECD sample, 83 per cent of firms are from developing countries.
[7] The peak centred around the CCP value of 6.7 is more pronounced for the OECD distribution, indicating that more enterprises in OECD countries converge to the mediocre CCP. More than 30 per cent of the firms in the OECD sample are from the US. Thus the result can be associated with the discussed negative effect of Trump’s presidency.

convergence process in carbon performance across firms in non-OECD (developing) countries. Our findings are consistent with Cheng et al. (2023), who document a more (less) significant decline in the dispersion of CCP across OECD (non-OECD) countries post-Paris Accords. Furthermore, the results align with Li et al. (2020), who document faster per capita carbon emissions convergence among developed vis-à-vis developing countries.

The illustrated results can be associated with companies headquartered in developing countries relying primarily on fossil fuels, facing loose environmental regulations and higher costs of improving carbon performance. Moreover, to meet strict environmental rules, public companies from rich (OECD) countries *outsource* their emissions to manufacturing firms in developing countries (e.g., Singhania and Saini, 2023). Lastly, the OECD members are democracies, thereby the results observed in Figure 7 are consistent with prior studies documenting the significantly negative effect of democratic political systems on countries' carbon emissions (e.g., Chou et al., 2020) and emissions efficiency (e.g., Muttakin et al., 2022).

Figure 8 illustrates a worryingly deep trough in the MPP for the OECD sample of firms occurring around the CCP value of 6.8 and reaching the net upward mobility probability value of -23 on the vertical axis. Notably, this trough resembles troughs in the MPP for the post-Paris Agreement period (Figure 4) and the North American region (Figure 6). Given that the US firms account for over 30 per cent of the OECD sample, while Trump's presidency largely overlaps with the post-Paris period, we argue that the troughs in Figures 4, 6 and 8 could all be associated with the outlined deleterious effect of Donald Trump's policies.

[Insert Figure 8 here]

4. Conclusions and policy implications

Global enterprises account for 40 per cent of carbon emissions worldwide. As fittingly argued in the literature (e.g., Cheng et al., 2023), the improvement and convergence of corporate carbon performance (CCP) to a higher level are the critical conditions necessary to achieve the target of limiting the temperature rise. However, it remains uncertain and unexplored whether global corporations exert efforts to improve their carbon performance. Given the above background, this study is the first to examine transitional dynamics and long-run convergence behaviour of global enterprises' carbon performance by employing two display tools of the DDA. Our analysis covers 19,913 public companies from 76 countries during the 2010-2019 period. Therefore, the research scope of this paper is much broader than prior studies focusing on aggregate carbon emissions from countries. Specifically, we compare the CCP convergence patterns (1) before and after the Paris Agreement, (2) among firms from OECD vis-à-vis non-OECD countries, and (3) across world regions. Implementing the MPP tool expands the depth of our research by introducing a new (otherwise unachievable) investigative angle within the DDA framework. Thus, we fully address the research objectives and deliver nascent evidence which contributes to the literature and can be helpful to policymakers and business leaders.

There are four main findings. First, regardless of the period of investigation (pre- and post-Paris Agreement), OECD affiliation, and regional location, the results suggest that in the long run, most publicly listed firms are on the convergence path toward the highest carbon performance (CCP value of 10). Moreover, only a tiny fraction of global enterprises will have poor carbon management proxied by CCP values ranging from zero to 5.5. Such results evidence collective efforts of international firms in transition to net zero and aligns with a fast-growing number of public companies announcing ambitious "science-based" targets for GHG emissions in the wake of the Paris Agreement. Second, in all samples, we document the emergence of a convergence club around the mediocre CCP value of 6.7. Third, the long-run convergence towards the highest CCP is nearly twice as significant in OECD compared to the non-OECD sample of firms and more significant after the Paris Climate Accords. On the same note, intra-regional convergence towards the top CCP is the most (least) significant in Europe & Central Asia (East Asia & Pacific). Fourth, the largest group of enterprises from the North American sample cluster around the mediocre CCP value of 6.7. Furthermore, the worst performers (with CCP values between zero and 3.2) in the North American region are the least likely to improve their carbon performance in the coming years, whilst firms with mediocre CCP from 6.7 to 7.2 have the most significant probabilities (up to 39 per cent) of future deterioration, thereby meriting the top spot in the *policy priority list*.

The results evidence collective efforts of global firms in transition to net zero and align with a fast-growing number of public companies announcing ambitious "science-based" targets for GHG emissions in the wake of the Paris Agreement. However, different paths to long-run convergence in CCP, depending on the regional location and economic development, suggest that future environmental policies should reflect diverse convergence behaviours rather than follow the *one-size-fits-all* approach. The observed least convergent path in the East Asia & Pacific sample is consistent with more manufacturing firms (operating in developing countries from this region) relying primarily on fossil fuels while facing loose environmental regulations and technological limitations. Thus, after deploying easier and cheaper options, further CCP enhancements would require advanced technologies to upgrade or replace the equipment, making it too costly. Moreover, we connect the results with *outsourcing* corporate emissions from high-income to developing countries with loose environmental regulations. In other words, the results suggest a loophole in global environmental law exploited (through regulatory arbitrage) by corporations from rich countries. The arbitrage, in turn, highlights the need for better international cooperation and coordination among policymakers to mitigate factors hampering climate goals. Finally, East Asian economies have sizeable untapped potential regarding the endowment of renewable energy sources (Dogah and Churchill, 2022). Thus, we advocate increased efforts to develop the infrastructure and policies aiding local firms in a fast-track (affordable) transition towards renewable energy and away from carbon-intensive fossil fuels. Additionally, multilateral agencies such as the World Bank, International Monetary Fund, and United Nations should support developing countries to remove their bottleneck in achieving higher CCP.

We argue that North American firms' relatively poor and disappointing carbon management can be associated with Donald Trump's reversed policy towards climate change. Fortunately, the US government led by Joe Biden demonstrates a more embracing approach towards climate change and a willingness to engage in carbon reduction targets. However, the reversal of CCP done by the previous administration will take years to unwind. Based on the dominating Republican and right-wing values among corporations in the southern and mid-west regions of the US, where fossil fuel is a significant source of income, CCP improvement will remain a challenge. Summing up, our results indicate that structural and regulatory differences between developed and developing countries and politics have a significant bearing on transitional dynamics and the long-run convergence of CCP. Future policies to motivate and coordinate decarbonisation in firms across countries should consider such differences.

One limitation of this study is that the analysis ended in 2019. Given significant developments in the global political and economic environment ex-post 2019, a follow-up study re-examining the CCPs' long-term evolution is advisable. Specifically, since 2020 we have witnessed the democratic US president (Joe Biden) making a U-turn towards environmental policies, the Covid crisis, conflict in Ukraine, energy shortage with a coal revival in the EU, and China's pledge to carbon neutrality. It could be worthwhile to explore whether the Covid crisis and the geopolitical conflict lead to more divergences in CCP in the global market or whether more commitments from the US and China to carbon neutrality encourage the convergence to high-level carbon performance globally. Our findings suggest that firms in the US have unique divergent carbon performance, which could be the outcome of contrasting carbon management of firms headquartered in the Democratic vis-à-vis Republican states. Therefore, another future avenue of research worth exploring is a detailed analysis focusing on US cross-state corporate carbon performance. In this study, we examine the convergence-divergence patterns of CCP across regions. However, firms that rely more on fossil fuels (e.g., chemical, metal and cement industries) could exhibit a separate convergence path to lower CCP than firms in other industries (e.g., services) as it is more costly to improve carbon performance. Thus, a cross-industry study of CCP would contribute to the literature and benefit the decision-makers in identifying which sectors require the most urgent environmental policies. Lastly, our study reveals that the MMP tool within the DDA framework can provide a new angle to examine the convergence patterns. Therefore, further studies using other convergence methods (e.g., beta, sigma, stochastic) could augment the depth of the analysis by applying MPP.

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Table 1: The number of publicly listed companies annually

Year	N	OECD	Non-OECD	East Asia & Pacific	Europe & Central Asia	North America	Other
2010	1,886	1,706	180	576	587	648	63
2011	1,877	1,715	162	591	594	637	42
2012	3,025	2,623	402	780	693	1,346	174
2013	7,407	6,028	1,379	1,501	1,770	3,207	822
2014	7,628	6,348	1,280	1,416	1,800	3,553	758
2015	7,515	6,002	1,513	1,486	2,067	2,982	865
2016	11,549	9,160	2,389	2,194	3,083	4,692	1,353
2017	12,463	9,813	2,650	2,502	3,414	4,854	1,463
2018	14,404	10,192	4,212	3,751	3,611	4,854	1,926
2019	14,982	10,410	4,572	3,965	3,728	4,903	2,125

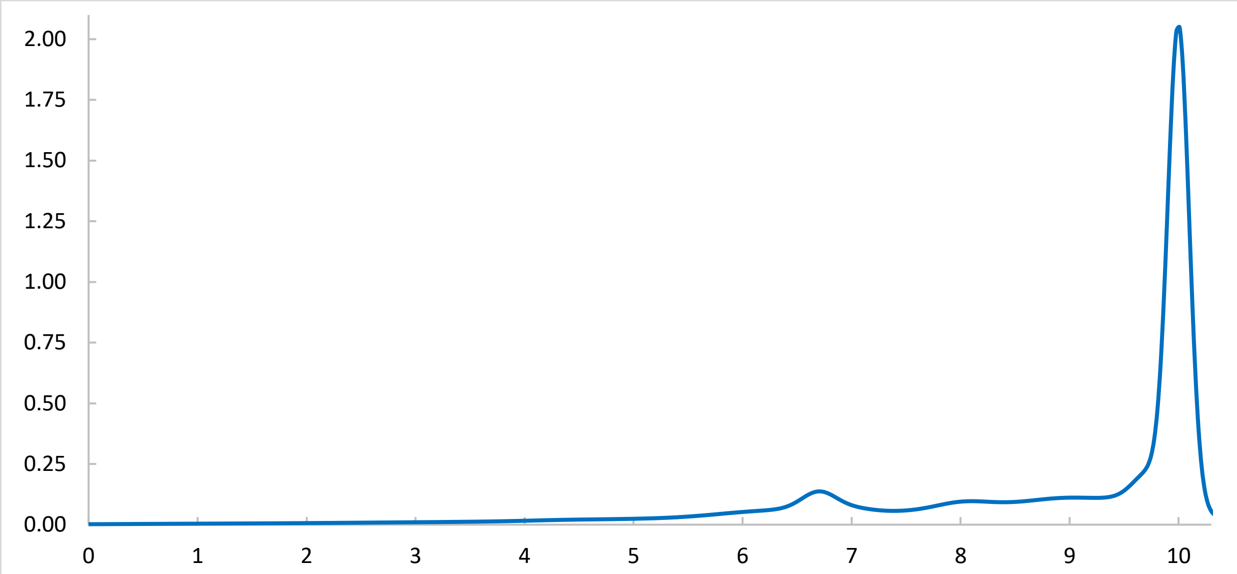
Source: MSCI IVA database and authors' calculations

Table 2: Annual average carbon emissions score across groups and in a global sample

Year	World	OECD	Non-OECD	East Asia & Pacific	Europe & Central Asia	North America	Other
2010	4.90	4.99	4.02	4.93	5.48	4.42	4.60
2011	5.14	5.22	4.31	5.11	5.72	4.70	4.55
2012	6.02	6.13	5.30	6.10	6.80	5.68	5.47
2013	7.04	7.13	6.69	6.89	8.05	6.54	7.14
2014	6.98	7.03	6.75	6.94	8.13	6.37	7.15
2015	7.10	7.20	6.72	7.14	7.78	6.63	7.07
2016	7.31	7.27	7.49	7.46	7.98	6.65	7.80
2017	7.44	7.40	7.61	7.56	8.03	6.81	7.92
2018	7.40	7.44	7.30	7.27	8.05	6.87	7.74
2019	7.36	7.42	7.23	7.19	8.01	6.85	7.67

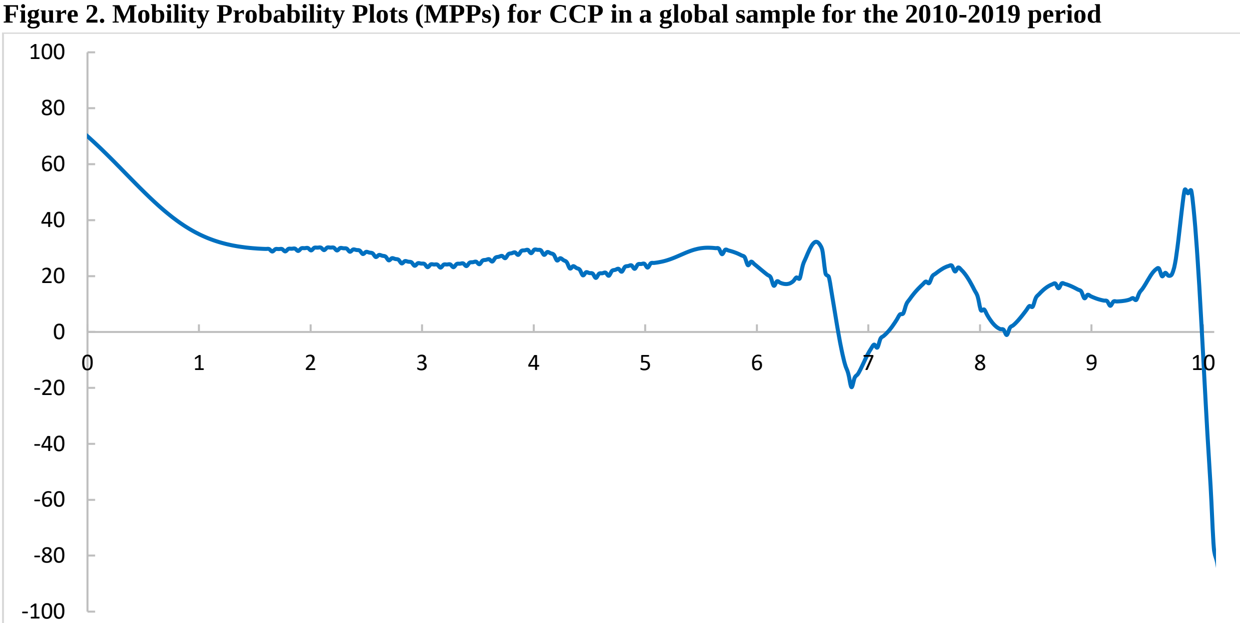
Source: MSCI IVA database and authors' calculations

Figure 1. Ergodic distributions for CCP in a global sample for the 2010-2019 period



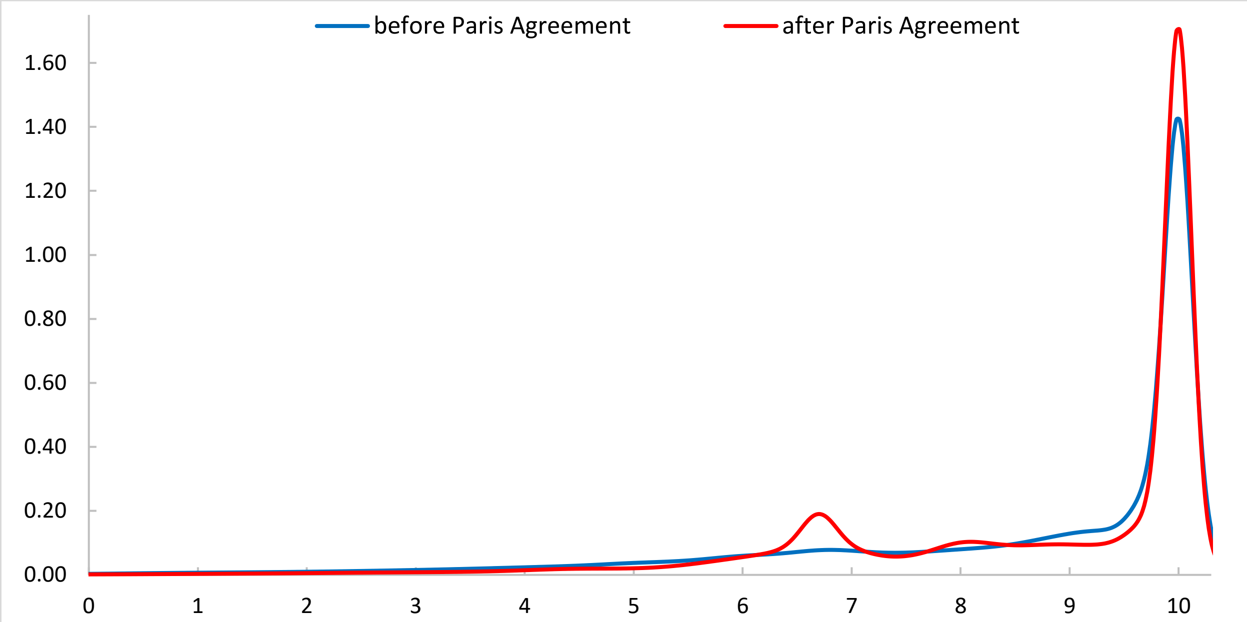
Note: The horizontal axis represents CCP while the vertical axis represents the proportion.
Source: Authors' calculation.

Figure 2. Mobility Probability Plots (MPPs) for CCP in a global sample for the 2010-2019 period



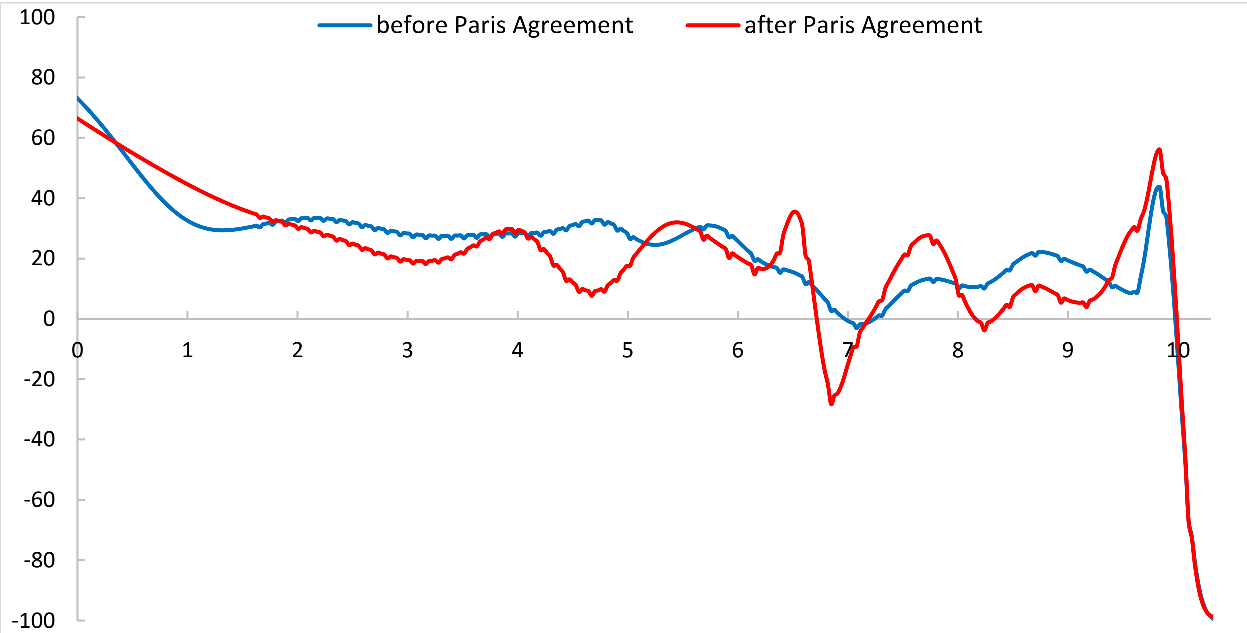
Note: The horizontal axis represents CCP and the vertical axis represents the MPP.
Source: Authors' calculation.

Figure 3. Ergodic distributions for CCP before and after Paris Agreement (2010-2015 vs. 2016-2019).



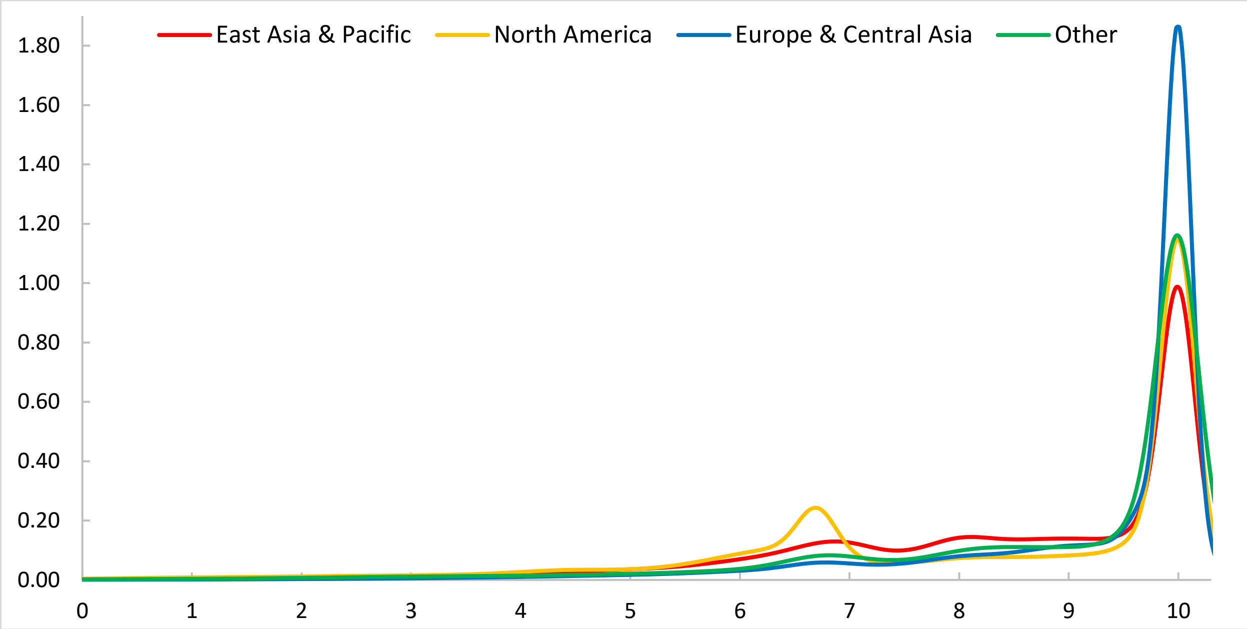
Note: The horizontal axis represents CCP while the vertical axis represents the proportion.
Source: Authors' calculation.

Figure 4. Mobility Probability Plots (MPPs) for CCP before and after Paris Agreement (2010-2015 vs. 2016-2019).



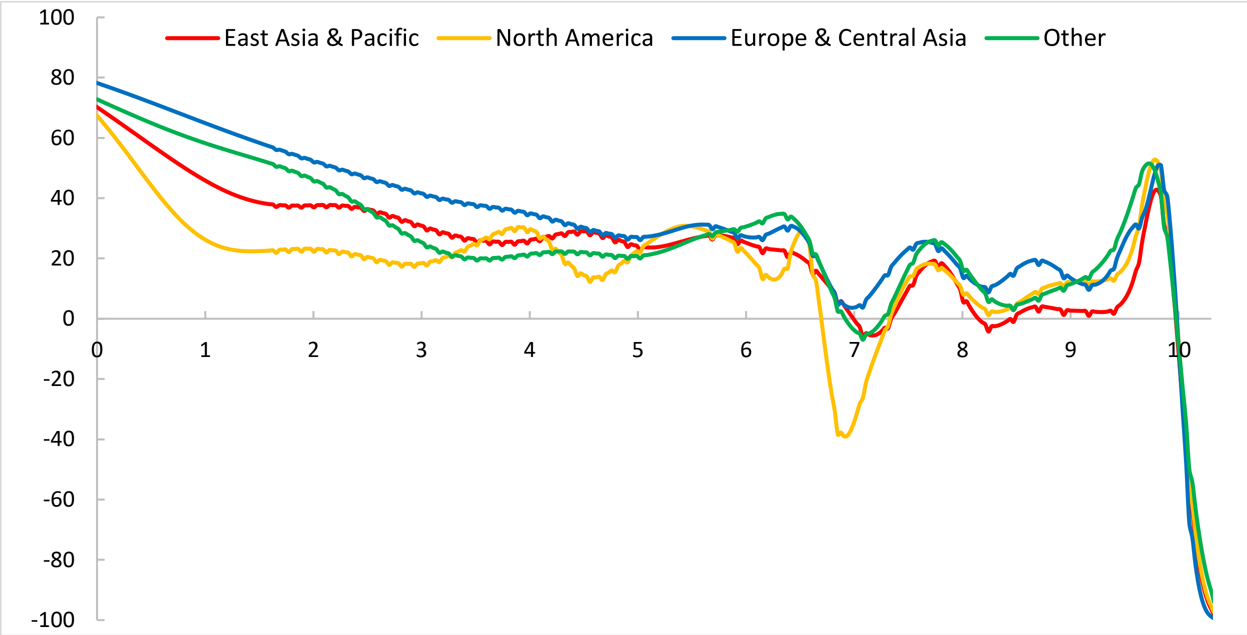
Note: The horizontal axis represents CCP and the vertical axis represents the MPP.
Source: Authors' calculation.

Figure 5. Ergodic distributions for the CCP across different regions.



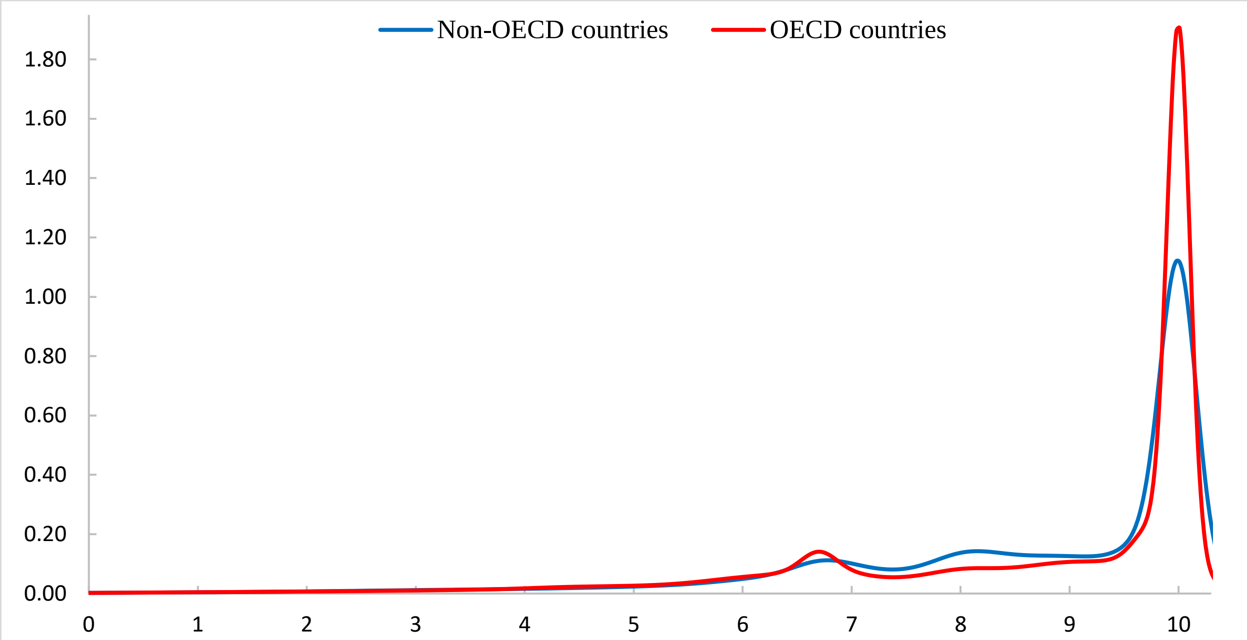
Note: The horizontal axis represents CCP while the vertical axis represents the proportion.
Source: Authors' calculation.

Figure 6. Mobility Probability Plots (MPPs) for the CCP across different regions.



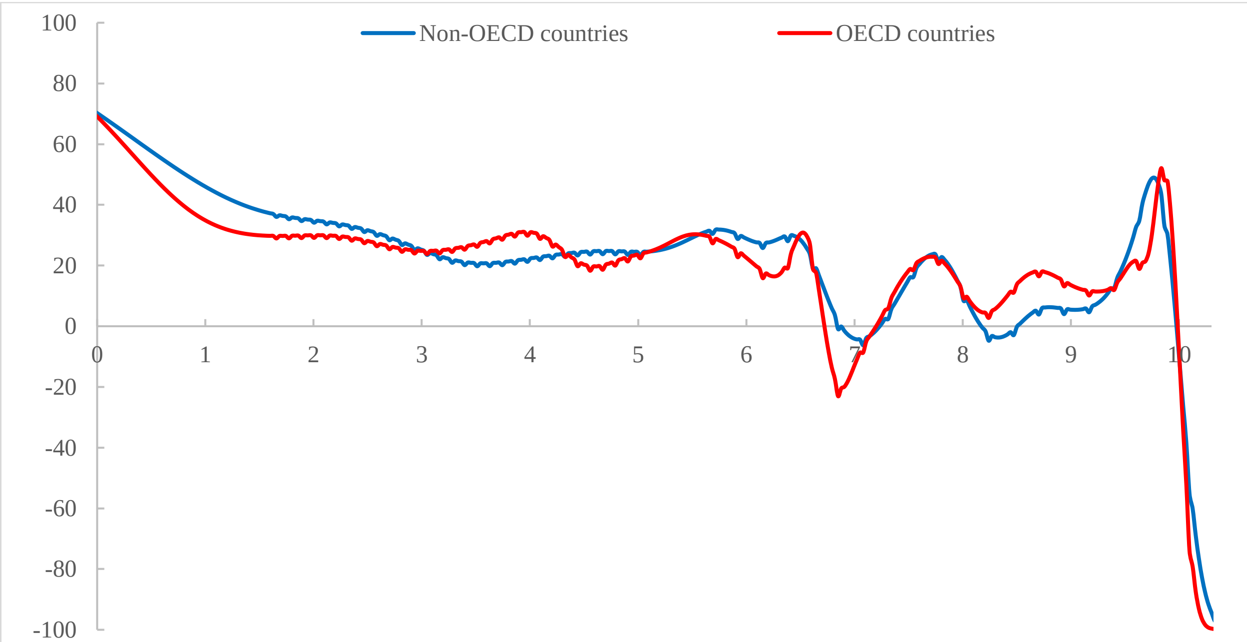
Note: The horizontal axis represents CCP and the vertical axis represents the MPP.
Source: Authors' calculation.

Figure 7. Ergodic distributions for the CCP in OECD versus non-OECD countries.



Note: The horizontal axis represents CCP while the vertical axis represents the proportion.
Source: Authors' calculation.

Figure 8. Mobility Probability Plots (MPPs) for the CCP in OECD versus non-OECD countries.



Note: The horizontal axis represents CCP and the vertical axis represents the MPP.
Source: Authors' calculation.