The Triplet Dynamics of Carbon Emission, Economic Complexity, and Income Inequality and its Optimization: a Global Panel Model Perspective

Authors

Zhen Ye[a b], Yite Zhu[c]

[a] *The Bartlett School of Sustainable Construction, University College London, London, UK*

[b] *The School of Economics & Wang Yanan Institute for Studies of Economics, Xiamen University, China*

[c] *The PBC Finance School, Tsinghua University, Beijing, China*

Abstract

The article analyzed a triplet link between carbon emission, economic development, and income inequality. Carbon neutrality, or even reductions, have often been viewed as costly economic endeavor, and carbon inequality is shown to have link with income inequality. Here we show through a global panel data set that carbon emission can be reduced without costing economic growth or inequality. The research utilized the Economic Complexity Index (ECI) and the indicators of inequality to illustrate a triplet dynamic linked to carbon emission. The findings suggest an optimized route for the carbon neutrality based on certain stylized development trajectories which highlight the co-existence of Veblen and Pareto effects, suggesting that policy makers need to be fully aware in designing a carbon neutral national economic development strategy.

Keywords:

Carbon neutrality, economic complexity, income inequality, Veblen effect, Pareto improvement

Highlights

- We study economic complexity index and inequality indicators to establish link between carbon emission and the quality of economic development with a global panel data of 125 countries, from 1964 to 2017.
- Reducing carbon emission, maintaining economic development, and tackling income inequality can coexist and manifest through Veblen Effect and technological effect, thus forming a Pareto improvement.
- Development trajectory of certain countries suggest that escaping poverty trap by increasing the diversity of production domestically to elevate economic complexity

index is an essential first step towards economic development and carbon neutrality.

Introduction

Recent researches have been increasingly focused on the realization of carbon neutrality, which is to reduce the carbon emission to zero. The Environmental Kuznets Curve (EKC) proposed in Dinda (2004) showed us the environmental cost of the development is an inverted U-shape function of development stage, meaning it goes up gradually before falling down, called technological effect, as an economy becomes affluent, called technological effect. The discussion concerns, thus, not just global environment preservation, but also country-wise economic development, a discussion of income and equality. Income and carbon are expected to be positively related. Several papers succeeded in linking emission to growth and gross domestic product (GDP) (Al-Mulali et al., 2013; Huang et al., 2008; Ozturk and Al-Mulali, 2015a), and Zhang & Cheng (2009) gave strong causality result that energy consumption and carbon emission does not determine growth. Meanwhile, results are sensitive to sample selection and statistical techniques (Huang et al., 2008; Payne, 2010). The EKC have relatively strong empirical support (Ajmi et al., 2013; Aung et al., 2017; Balıbey, 2015; Can and Gozgor, 2017; Choi et al., 2011; Oshin, 2014; Özokcu and Özdemir, 2017; Zhang, 2018), the question is whether growth or GDP alone can explain the trade-off between development and environment, let alone carbon.

Literatures in the field have covered widely on the connection between carbon emission and measures of economic development quality, including income inequalities, with various choice of proxy variable selection, scale of data, or model settings. Two of these variables are of particular research value, the economic complexity index (ECI) and the Gini index.

ECI is measured by the diversification in categories of an economy's export list (Hidalgo and Hausmann, 2009). It concerns the flexibility of production of an economy on its own, its ability to survive macroeconomic shocks. It is thus representative of the development quality and diversification potential of an economy, and is a plausible proxy to test for EKC concerning carbon problem. It is of strong predictive power of income inequality (Hartmann et al., 2017a; Hidalgo and Hausmann, 2009). Considering its link with income and consumption, it is a of value to be included in a triplet dynamic with carbon and income inequality.

Linking income inequality with carbon emission is no new problem (Teng *et al.*, 2011) Literatures have argued that income inequality is linked to carbon emission and its distribution policy in a potentially dynamic way (Cantore and Padilla, 2010; Duro and Padilla, 2006; Heil and Wodon, 2000, 1997; Padilla and Serrano, 2006). The problem is that neither has the theoretical discussions or empirical works reached a common ground (Liu *et al.*, 2020), which is the directional of impact. Some findings showed that higher income inequality leads to higher emission. A crucial chain of logic standing behind this statement is that the poor, under a more unequal society, consume aggressively to emulate the rich, signaling their social status albeit not necessarily optimal for welfare. The phenomenon is called Veblen effect (Bagwell and Bernheim, 1996; Dahm and Fassnacht, 2018; Veblen, 2018, 2005) and will thereby lead to inefficient energy consumption and luxurious carbon emissions. In contrast, many regional studies have argued that income equality leads to carbon inequality, and renders the distribution of carbon emission left-skewed on the income axis (Hübler, 2017).

The research gap exists in that little work has been done to establish a multi-variable dynamic involving carbon and development metrics, not to mention a work on global scale. While regional studies or static comparison of a limited number of entities help to uncover empirically the dynamics, they cannot be generalized to a global perspective (Abdon and Felipe, 2012; Al-Mulali et al., 2013; Alvaredo and Gasparini, 2015; Basu and Stiglitz, 2016; Choi et al., 2011; Fang and Wolski, 2019; Ferraz et al., 2018; Hartmann et al., 2017b; Oshin, 2014; Palma, 2011; Wolde-Rufael and Idowu, 2017; Zhang, 2018).

A study of a broader scale using a concise model to study the triplet dynamics gives this paper a place in filling the niche in the field. This paper tries to bridge the gap by explaining, through a triplet dynamics of carbon emission, economic complexity, and inequality indicators, a potential Pareto improvement that boosts economy while reining in the environmental damage. Specifically, the research used data over 5 decades in 116 countries, on which if the EKC and Veblen effect could be verified, a Pareto optimization improving economic development and environmental preservation for any specific economy would arise. Additionally, the paper uses the triplet to show the development trajectory of economies in balancing carbon outlets and economic development. The paper intents to provide policy suggestions for potential carbon neutrality strategy in cohesion with economic development.

Model and Results

We propose our hypothesis as follows:

H1: ECI quadratically influence the carbon emission, the coefficient for the quadratic term should be negative to represent the EKC, i.e., technological effect exists.

H2: The adjusted Gini index has positive impact on the carbon outlet, i.e., Veblen Effect exists.

Our choice of model is the panel model to accommodate the data, which uses ECI, quadratic term of ECI, and the adjusted Gini index as our main regressors. The adjusted Gini index is composed of Gini index data and similar inequality measurement to complement for missing data as described in the appendix. Control variables include GDP growth, GDP per capita, region dummies and income group dummies. Both dummies are given by the world bank database. To further analyze the development pattern of countries, we apply k-means clustering analysis to the ten yearly-phased data. As such, we aim to identify whether certain countries have similar traits in the triplet for each decade, therefore showing similarities in their trade-off decisions in terms of economic development and environmental preservation. If any economies jump to different clusters, the economy succeeded in altering the triplet characteristics, but the jump can be lasting or transitory.

We apply a series of panel models that use carbon emission per capita as the dependent variable. The results are visible in Table 1. The results suggest strong significance for the variables of interests in our main model, i.e., model (3) and (4). To verify the robustness of the model result, auxiliary regressions, i.e., model (2), (6), (7), are created and a series of tests (Table 3) are performed to help solidify the robustness of the fixed effect model result we summarized above.

For starters, tests suggest that fix effect models outperform the plain OLS model or pooling model. The random effect model is no better than pooling model according to Breusch-Pagan test. Nor does Hausman test support random effect model over fix effect model. All tests concur that the fix effect model is a better choice for our data. Although Breusch-Pagan test for time effects showed that time-fixed effect is recommended, the unbalance nature of our data stops us from acknowledging the reliability of this test result. We will hereafter focus on fix effect model framework, i.e., model (3).

Table 3. Test results

Test	P value
F test for individual effects	2.27E-298
Hausman Test	3.67E-09
Lagrange Multiplier Test - (Breusch-Pagan) for unbalanced panels	0.793
Lagrange Multiplier Test - time effects (Breusch-Pagan) for unbalanced panels	0.00E+00

Hypothesis 1 and 2 is evaluated as verified by the main model, (4). Specifically, ECI negatively, quadratically affects carbon emission per capita, i.e., technological effect exists; meanwhile, Veblen effect is significant. By and large, our results agrees significantly with technological effect where development reduces environmental harm, and agrees significantly with the Veblen effect (Veblen, 2005), while controlling for

ECI and development metrics like growth and GDP per capita. Coefficient estimates for the ECI and its quadratic are both significantly negative, suggesting that controlling for other variables, countries with a ECI more than -2.5 is entering technological effect theorized in Dinda (2004), where economic complexity will help drastically reduce carbon emission per consumer and is not done directly through reducing income inequality.

ECI and Gini both have separate effect on the carbon emission, justifying the triplet dynamics. Not only the main model shows that EKC and Veblen effect are present, almost all our models under various settings agree with this estimation result, with varying scale of the effect. The model disagrees with the strong causality found by Zhang & Cheng (2009) between GDP growth and energy consumption, possibly decomposing the effect into technological effect and Veblen effect. Our model is prone to the theory that the diversification of production and exports, combined with more equal income distribution, have more significant impact on carbon footprints.

As for other controlling variables, coefficients are significant and directions of them are as expected. GDP per capita as a significant effect on carbon emission. It is safe to conjecture that a higher individual income leads inevitably to the increase in the carbon emission. As for regions and income groups, every model agrees with strong significance some general statements. Ruling out all forces above, all regions emit less than the North America region, and all income groups emit more than the low-income group. With several comparably more fossil-fuel-concentrated economies, Middle East and North Africa region comes in second place and consumes 5 tons less per person each year. Our model recognizes little difference between low-income group effect and lower-middle-income group effect but suggests that a consumer in upper-income or higher-income countries consumes on average 3 to 8 tons more per person on a yearly basis.

To verify the robustness in inequality indicator construction, we checked the model when Gini index is calculated as the arithmetic mean of all Gini index surveys and UTIP data for any the time point in a certain nation. The above results are still valid in direction and significance. Please see Table 3.

To further verify the robustness of our model, cluster-robust standard error (CRSE) is introduced in model (5) to cope with heterogeneity and improve estimate efficiency. CRSE approach is efficient given that sufficient number of clusters exist and each cluster contains enough number of samples (Cameron and Miller, 2015), which was satisfied here because of the sample size. The CRSE approach strongly agrees with the findings of model (3). To add to the reliability of model (3), random effect model (4) and the least-squares dummy variable (LSDV) model (2) agrees with model (3) on signs of coefficients.

Lastly, we applied k-means clustering analysis to the ten yearly-phased, summarized panel data to find out whether clustering of similar countries in terms of the triplet changes during the five decades. Firstly, we summarized the normalized mean of the carbon outlet per capita, the ECI, and the Gini index for the five decades from 1964 to 2017. K-means clustering analysis is then performed on the data divided into five periods. The estimation of parameter k is obtained through the classic elbow approach and the Silhouette approach for multi-perspective analysis. We then create the data visualizations for the five periods and colored the countries consistently according to regions for better understanding of results. In addition, clusters are circled out by convex polygons on each ten-year sample graph. The results are visible graphically in Figure 1-5, and the relevant findings will be presented in discussions. As will be discussed later, the clustering analysis summarized for several development trajectories in terms of the triplet.

Discussion

Carbon reduction in combination with economic growth and promoted equality

For the most part of the five decades in question, the developed world hovers more often in the high ECI, low Gini zone, whereas the developing world spend most of the five decades in, or trying to escape, the low ECI, high Gini zone. What matters is perhaps not the negative correlation between the ECI and the Gini (Hartmann et al., 2017a), but the potential for countries to optimize both in development by improving ECI for development resilience and in income inequality to evade Veblen effect. These measures will benefit the economic development, whereas reduces the carbon emission, thereby forming a Pareto Optimization where everyone earns. We project the median of the ECI and the Gini during 2003 and 2017 for each country on a Gini-ECI plane, with the size representing the median of emission per capita in Figure 6.

Figure 6. Emission Per Capita on Gini-ECI plane, 2003-2017 average

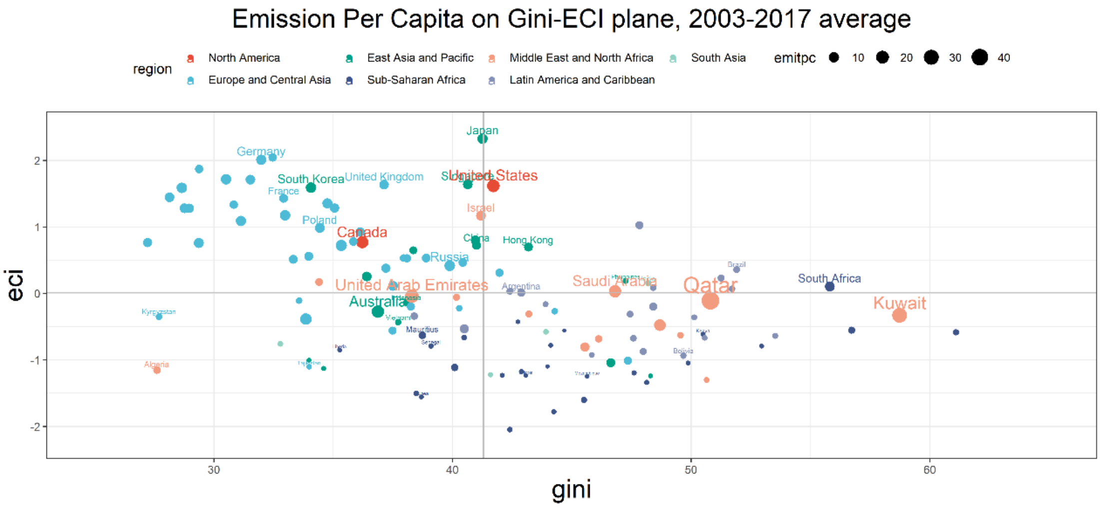


Figure 6, combined with our panel models, shows that the countries in the high ECI, low Gini zone has relatively lower emission, locally, since we cannot project income per capita on the graph. There are exceptions, e.g., some developing countries have low ECI, high Gini, but lower emission compared to those with close but not as bad ECI and Gini. The carbon emissions of these exceptions are more often than not dominated by their low average income level. In general, the link of the emission-ECI-Gini triplet points to an optimal solution to both the economic development and income inequality by focusing first on the economic complexity.

As our data shows, many economies are entering the technological effect, where development helps reduce carbon outlets, matching EKC hypothesis. It may seem awkward since technological effect was predicted to occur with highly developed economy. The occurrence technological effect can be a result of technological spillover, where rising economies enjoys the positive externality of technological product of the developed world. Simply diversifying the production activities makes an economy resilient towards unexpected shocks and allows for various means of energy consumption, reducing the reliance on fossil fuels, therefore the carbon.

Inequality is another factor to optimize for. Though regional researches suggested that a left-skewed income distribution reduces the source of energy consumption (Baloch et al., 2018; Coondoo and Dinda, 2008; Heerink et al., 2001; Nikodinoska and Schröder, 2016; Ravallion et al., 2000), our global picture suggests that a comparably unequal economy can always find its way to emit carbon less efficiently. The underlying results can be the negligence on improving energy consumption efficiencies of the people due to inequal social status induced by income gap. People have way less attention to focus on environment protection when they are struggling to earn a living and change their lives. The **Veblen effect** (Veblen, 2005) stands to be a more realistic explanation for inequality-carbon dynamics.

The results of model with only the ECI but no Gini also help clarify a myth between development and environment protection. Some fear that rapid development is achieved at the cost of carbon emission, which is correct according to the significantly positive contribution of pure economic growth to carbon outlet in models. Our model results show that this conclusion is, nevertheless, potentially a result of omitting the effect of any measure of income inequality and the more complex mechanism utilizing economic complexity to control carbon emission. Comparison between these omitted-variable models and our main model should nurture confidence for policy makers. As long as ECI and income inequality are in check, growth, however large, will not lead to a worsen environment.

Though the emission per capita will go up eventually as the average income amounts, ceteris paribus, the Pareto optimization discussed so far still provides chances to greatly slow the pollution along the way to economic development. The next pertinent question is whether there are specific road maps to follow in this optimization.

Development Trajectories and the carbon dilemma for the late-starters

To put the above finding in perspectives, we studied the development track of all countries and economies in the past five decades on a Gini-ECI plane, attempting to see how economies balance between the triplet of emission, ECI, and Gini, i.e., development and environment. Here we further employed cluster analysis to identify the situation where countries can simultaneously maintain a certain degree of economic growth while decreasing carbon emissions.

The k-means cluster analysis provides an angle for our conjectures. Equilibrium with higher ECI, lower Gini, and lower carbon emission is the general goal for every economy, as our model suggested. In reality, Europe and Central Asia regions are full of economies characterized as such for most of the five decades. They are usually separated from the developing world, including mostly Sub-Saharan African, Middle East and North African, Latin American and Caribbean, South Asian countries. Most of these developing countries can be observed with little movements in the high ECI, low Gini areas. Once they improve on both factors, their emission level drops accordingly. Although this is not to say Europe and Central Asia have reached the most efficient equilibrium, they still constitute encouraging goals for developing world in terms of the triplet.

The story for East Asia and Pacific area is yet an uncanny one. The clusters of these countries have shifted several times along the decades. During the first decade between 1964 and 1975, most East Asian countries are regarded as equals of the developing world, with a few exceptions, Japan and China. It was a time when they maintain an unremarkable ECI and Gini level. The next decade witnessed some economies rises, with improved ECI and sequentially lessened Gini. Among them, Hong Kong, Singapore, South Korea, and New Zealand are clustered either with the European area, or with some upper-middle income or thriving peers like Spain, Ireland, Israel, Argentina, South Africa. In the following decade, most of them are on par with the European area and Central Asia, surpassing Canada, Russia and Australia, leaving the developing world behind. From 1996 to 2005, this trend persists while Japan become the exception, which we will talk shortly afterwards. This is a period during which the world is roughly divided into the Europe-US-East-Asia centered cluster and rest-of-the world cluster.

We can see that this area is the golden example of development path. The economies in this category usually started plain, but found their way into a higher level of ECI, and maneuvered their way out of undesirable inequality to cash in the Veblen effect right after or even alongside the ECI boost. All the process started with an improvement in ECI and an increased level of carbon emission due to sudden income surge. The ECI boost is usually accompanied by technological effect that reduces carbon emission. This effect explains the coexistence of development and stable average carbon outlet of East Asian economies.

The clusters display Veblen effect on a macro scale, and the growth of ECI slows down. The regional increment of per capita emission in the East Asia and Pacific area, accompanied by stable ECI and increment in Gini, can be viewed as a long-term attempt to meet the existing consumption standards, or life standards in a sense, in the two comparably developed areas, North America, Europe and Central Asia. The absolute level of average emission suggests that the North America, Europe and Central Asia have been maintaining a relatively high amount of per capita carbon outlet given the relatively small population. Albeit effort to reduce carbon emission through stably high ECI and relatively low Gini index, their higher emission signals a more luxurious mode of consumption standard. The emulation of developing countries towards developed economies exists, since after ECI of the East Asia and Pacific economies stabilizes in the recent decade, the carbon footprint still increases with Gini. The carbon footprint of some gradually lowers as they settled near the high ECI, low Gini zone.

Some exceptions like China and Japan are paving their way towards the USA, which harms their environmental health inevitably. The United States, rather than being viewed as a peer in the Europe cluster, is constantly isolated as one cluster of its own. Its biggest distinction between other high ECI, developed European peers is an observed deterioration in income inequality, with some fluctuations. As it moves along this path, its carbon footprint follow the reasonable trend and increases. The phenomenon is a sign of existence of Veblen effect, where inequality motivates emulation and inefficient consumptions. What cautions the reader is that China and Japan, are having similar problems, with elevated but stabilizing ECI, elevated Gini, and elevated carbon outlets. As the previous paragraphs mentioned, the worst end of this trend is the Veblen effect taking place on a truly global scale, where income inequality induced, inefficient consumption drives high carbon emission like there is no tomorrow.

The attempts of the greater developing world are not as desired for them. Ideally, the developing world aims to follow the example of the East Asia and Pacific area, but the reality constantly disturbs them from realizing the first crucial step, the elevation of their ECI level. Some were close to a success during 1976 and 1985, for instances, Israel, Argentina, India, South Africa, Mexico, Jordan. Their progress was short-lived. By the end of that decade, only Israel made it into the high ECI, low Gini zone, whereas the rest of the frontrunners from the Sub-Saharan Africa, Middle East and North Africa, Latin America and Caribbean, South Asia are re-clustered together. It symbolizes the start of two-decade-long struggle to break free from the group for all these countries. Some of them stays emitting the same level of carbon, while some worsens due to a more intense income inequality and a bad ECI.

The decade from 2006 to 2017 is the new era for the world. While the more developed European economies settled in a high ECI, low Gini zone, together with Japan, Korea, and Israel. Mid-tier developed European and Central Asia economies are mixed with Asia-Pacific economies and a few rising developing economies from Latin America and Caribbean area. Some of the developing world achieved lower emission by coping with inequality, but the vast majority of them are still in the low ECI, high Gini zone, with increased emission compared to themselves a decade ago. It suggests that reducing inequality first is a noble attempt, but a difficult path for ECI improvement or development overall.

To add to our perspective, Silhouette estimation approach constantly separate the countries into two clusters during all periods. Still, it pointed out the Kuwait, Qatar, and United Arab Emirates are the three nations frequently deviating from the rest of the world. This finding suggest that these three nations are marked with exceedingly disproportional carbon emission with regard to their economic complexity and income inequality. Given their circumstances in the feature space, they deserve to be analyzed separately for development strategies and policy suggestions, which is beyond the scope of this paper.

Policy Recommendation

As opposed to the usual perception of trade-offs between development policies and environmentally friendly policies, the work so far has suggested that increasing the ECI and lowering Gini can help reduce carbon emission via technological effect and Veblen effect. The development trajectory agrees with this suggested optimal development path, and the transition are often accompanied with lowered emission on average, if not for the sudden soaring of income. The path is of great value, since it provides an example for countries who have been fighting to get rid of poverty, inequality, and possibly desiring a lower environment externality. The hurdle for this practice lies in lifting the ECI on most occasions, and deserves the maximum focus.

Directly, economic complexity enables an economy to adopt a more diversified range of production, enabling the utilization of more energy source. Earlier literatures, through different angles, have argued that merely boosting the GDP growth for the developing world is no solution to their situation in welfare (Alvaredo and Gasparini, 2015; Morelli et al., 2015; Palma, 2011), not to mention carbon emission. As discovered in our cluster models, Kuwait, Qatar, and United Arab Emirates are frequently isolated from the low ECI world during the five decades, mostly because of their skyrocketing emission level per capita. These countries and similar economies are known for skewed focus on fossil-fuel-related industries, which is the reason for that high-rising carbon outlet.

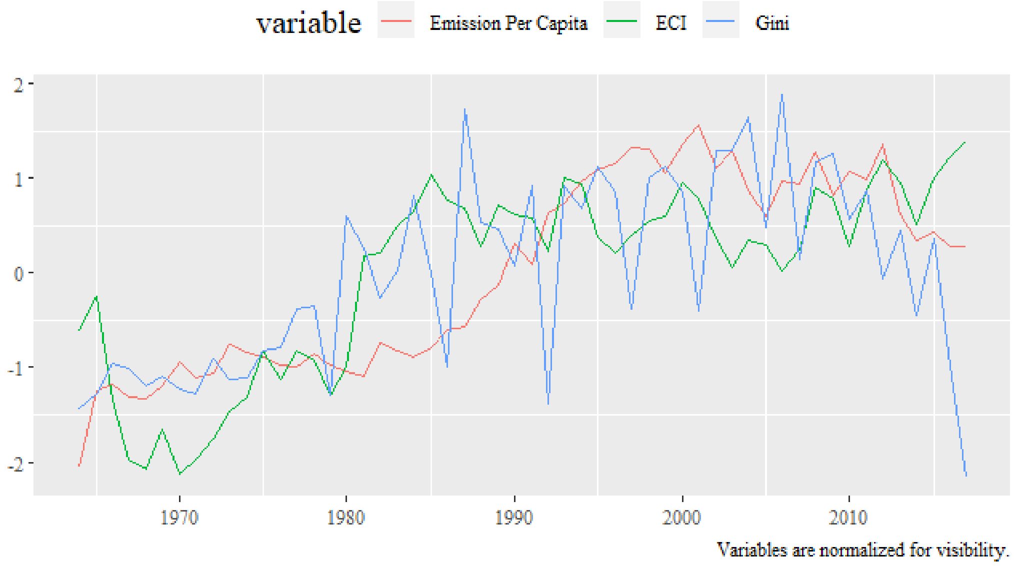
A wider range of production and export is not just about choices of production procedure or energy source, but also about the endogenous capability within an economy to thrive under different shocks, e.g., the Covid-19 crisis. Economic complexity can transfer not just into different production practices, but also into human capital or even aggregate demands to meet the trigger of industrialization (Pugliese et al., 2017; Carvalho & Rezai, 2016; Ferraz et al., 2018). The capability ensures a more complex source of income, a more sophisticated economic structure for industrialization, as well as nurturing human capital in distinctive industries (Lee and Vu, 2019). In other words, a stably high level of economic complexity gifts an economy with flexibility to expand on its good days and a stronger recovery ability to stand up from short-term shocks.

The flexibility in economic structure enables market participants to engage in different productions, thereby creating various opportunities to reduce poverty and income inequality. Improving the economic complexity is the first step to actually bring up the welfare of a country, and can be achieved environmentally friendly.

What comes following up should be the reduction of income inequality. Many of the Asia-Pacific economies maintained a stable level of carbon while enjoying the benefit of economic growth, due to the technological effect that reduces carbon emission. A number of them, however, were faced with income inequality problems. This is not a problem of their own, but also an existing problem for the USA as well. Veblen effect is, as our models suggest, a due problem for every economy to reach a high ECI, low carbon equilibrium, and the developing world should be prepared for the challenge. What seems to be working in Europe and Central Asia is their welfare system and open government pursuit. A system that rids citizens of critical survival concerns, together with chances to climb higher up on the social ladder, is suggested to be effective in eliminating the need for emulation and status-related consumption. To provide example for the bigger developing world, Ozturk & Al-Mulali (2015a) showed through a city-level model that municipal governance can be a key to carbon control. The capability of local governance in ruling out corruption and a better management in city planning can be the driving force for carbon reduction in the developing economy. What policy makers should further consider is the urbanization, a moderate level of which is beneficial to emission control (Shah et al., 2020), due to its ability to empower the local economic complexity.

Figure 7. Development track for Israel

Development track for Israel



A nation-level example can tell us a more specific story. Among all economies, Israel realized the threshold of its economy drive via elevating ECI along its development. During its development, the inequality goes up gradually, hedging off the decreasing effect of ECI on the emission per capita. As its economy settles into a good condition in the 21st century, it started lowering the inequality while maintaining a high level of ECI. The achievement is a falling emission from its peak in recent years. The example is a good reference to learn from for countries who try not to rid their people of rights of economic development while maintaining a range of environmentally friendly industrial policies.

Appendix

Methodology and Data

Data

The data we use is a fusion of information from multiple sources. The carbon emission data comes from the World Bank, as well as the GDP, income group and region categorization. Our panel includes the annual data points for 125 countries, through 1964 to 2017. The data points are not well balanced, especially with the Gini index. Thus, a model with the Gini index as regressor usually has 4,034 samples for the entire panel. Some auxiliary regressions in this paper leaved the Gini index out, and therefore contains 5316 samples to work on. As we have described above, the discrepancies in the change of carbon emission and GDP on both total and per capita level have suggested extra factors in their dynamics. Before we propose our hypothesis and model, we briefly describe our motivation, data collection and present descriptive analysis.

Per capita GDP seems to be able to explain the carbon outlet, Figure A1 shows a brute correlation between GDP per capita and average emission worldwide in the past five decades. The intriguing part of the data is that, the link is not linear, especially if we look at data for different economies.

The above correlation is deceiving, nevertheless. In Figure A2, the increment for the per capita emission in the North America, Europe and Central Asia are almost unrecognizable, even dropping in recent years. East Asia Pacific, Middle East and North Africa areas realized massive increase in average carbon outlet during the decades. The trend does not hold strongly for the per capita income according to Figure 3. While an observed increment in the average GDP in these leading carbon emitter nations is no surprise, the fact that per capita emission has changed non-proportionally with income is beyond explanation. Even if we use descriptive statistics in a total-amount fashion, the numbers still fail to add up (Figure A4-A5). This series of discrepancies points to some unconsidered factors. We suspect that there are other macroeconomic perspectives that can help explain the dynamics.

The economic complexity here is proxied under the presumption that a good representation of economic complexity of an economy is the embodiment of its diversity in production, therefore export. The natural choice of such is the Economic Complexity Index (ECI) from Hidalgo & Hausmann (2009). A higher ECI implies a higher diversification in categories of an economy's export list. A diversified export list brings about the diversity in the income of an economy's individual consumers.

The ECI level ranges between -2.25 and 2.5 for our entire panel sample. A negative note simply means an extreme lack of diversity in an economy's export repertoire. If we view the period as the time horizon of a social experiment, the ECI level serves as a semblance of initial condition or endowment for each country. For an average high-income country, the mean of its ECI is 0.92 for the past two decades, and 0.89 for the thirty-four years before that. The numbers for the middle-income countries and low-income countries can be found in Table 1 and are all below zero. In the recent two decades, situation has improved for the upper middle-income countries and high-income countries, and is further worsen off for the relatively less wealthy nations. When we look at this trend in the increasing gap from the perspective of regions, we can see from Figure A6 that East Asia Pacific and North America are the only two regions with improved ECI over the recent two decades. This gap in export diversity is another factor that renders the economy so different from each other, apart from plain GDP numbers and income inequality. Figure A7 gives more information in terms of across time distribution of the ECI for each region, and the regional advantage remains to be obvious.

Table A1. Ten yearly-phased-mean ECI by income groups

Income group	**1964-1998**	**1998-2017**
Low income	-0.8554420	-1.0175783
Lower middle income	-0.6322589	-0.7494670
Upper middle income	-0.2297148	-0.1331103
High income	0.8922191	0.9215886

To introduce income inequality into our discussion, we resort to the Gini index. The income Gini index contains the crucial information about income distribution among market participants in an economy. As argued by Cobham & Sumner (2013), Palma measure of income inequality, by taking into account the top 10 percent and bottom 40 percent of the households, can reflect more explicitly the status of inequality. The data accessibility constraints, however, remains to undermine the usability of the Palma measure, since the missing required data for its calculation is usually the same reason why the Gini index data is unbalanced. Since the two measures work virtually the same, the Gini index is sufficient for our analysis. The data source of the Gini index is mixed, for good reasons. The World Bank database possessed information about income distribution globally, which indeed gave us good reference for several years. Throughout most of our observation period, however, this source alone leaves us a highly unbalanced panel to work with. To complement for the data integrity, we resort to two extra sources, University of Texas Inequality Project (2015) (UTIP) and World Income Inequality Database (UNU-WIDER, 2020) (WIID).

The UTIP provides an estimated data on the inequality data based on Theil's T statistic. In principle, the estimation of this inequality indicator takes into account the population, industry pay, and income gap (University of Texas Inequality Project, 2015). Apart from filling in the missing values for some countries within our panel, it also provides more information beyond the scope of Gini index constructed by estimating the discrepancies between the income allocation and demographic distribution (Conceicao and Ferreira, 2005). After scaling, the data is compatible to be joined and used with the Gini index. The UTIP data made for losses of around 600 data points, aside from adding to the reliability of existing data.

WIID offers, though unbalanced, multiple sources for the analysis of income inequality. It gathers both data from the World Bank survey, but also surveys performed by the demographical department of local government, among some other surveys. Each entry, with some exceptions, usually comes with a survey quality score. The importance of the score is not negligible since the distribution of it, through kernel estimation, does not show normality and displays left-skewness for all income group data.

To attend to the reliability of all surveys, we summarize the weighted average of the

Gini index based on survey quality whenever possible, before averaging between the UTIP data if available. The main conclusions of this study are based on the weighted average Gini index to cope with the data contamination. To add to the robustness and consider the difference of the Gini index and the Theil's T index, we checked the result when using solely the data from the WIID. During the course of this robustness check, Gini index is calculated as the arithmetic mean of all entry of the time point at a certain nation. The model result, after verification, is not much different in coefficient direction or significance. A collateral benefit of this method is that it helped reduce the unbalanced nature of our data and improved the goodness of fit. We hereafter refer to our inequality index computed using the merge information from the Gini index and UTIP data as the adjusted Gini index for simplicity.

Hartmann, Guevara, et al. (2017) proposed that on a global scale, ECI is in negative correlation with the Gini index. Our data on the Gini index verifies this proposition in a sense. Inequality situation for different regions differs in mean level as it is with ECI, and is not normally distributed across time. Decomposing the data into income groups throughout the decades, we can see that, though slight, a decrease in inequality has happened across all income groups, except the high-income group (Figure A8-A9).

Model Choices

The empirical study of the three factors revolve largely around panel model, ARDL, VECM, GMM estimation and their subordinates (Can et al., 2020; Huang et al., 2008; Hübler, 2017; Kijima et al., 2010). Even for the most concise panel model, the question remains whether a fixed effect model or a random effect model should be developed, both of which has their merits and is unifiable under proper framework (Mundlak, 2016). A yet more applicable approach may be to choose not only based on the widely used Hausman test (Hausman, 1978), but also choose according to the characteristics of the data, by its amplitude of correlation and the size of the panel (Clark and Linzer, 2015).

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