The effects of technology intensity in manufacturing on CO2 emissions: Evidence from developing countries

Elvis Avenyo and Fiona Tregenna

Working paper 846

January 2021

The effects of technology intensity in manufacturing on CO_2 emissions: Evidence from developing countries*

Elvis Avenyo[†] and Fiona Tregenna[‡]

January 15, 2021

Abstract

Industrialisation is recognised as important for developing countries' growth and 'catching up' with advanced economies, but is also associated with harmful carbon dioxide (CO_2) emissions and hence with climate change. This poses a challenge to sustainable development, particularly for late industrialisers: how to industrialise while also mitigating CO_2 emissions. This paper investigates the effect of technology intensity in manufacturing on CO_2 emissions: is high-technology manufacturing less emitting than medium-technology and, in turn, low-technology manufacturing? We analyse this for a panel of 56 developing economies over the period 1991 to 2014, estimated using generalised method of moments (GMM). Methodologically, we adapt and synthesise the environmental Kuznets curve (EKC) and the stochastic effect by regression on population, affluence and technology (STIRPAT) approaches. We utilise two alternative measures of emissions: absolute and per capita volumes. Our results show that medium- and high-technology manufacturing are associated with higher emissions than low-technology manufacturing. In relation to the technology intensity of manufacturing exports, we find high-technology manufacturing to be associated with lower emissions than medium-technology manufacturing, and in turn low-technology manufacturing. These findings have important policy implications, suggesting that a shift towards more technology-intensive manufacturing may be a more

*Funding under the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation of South Africa (Grant No. 110691), through the Community of Practice in Innovation and Inclusive Industrialisation under the DST/NRF South African Research Chair in Industrial Development, towards this research is hereby acknowledged. We thank Erika Kraemer-Mbula for helpful inputs and Isaiah Magambo for research assistance.

[†]Technology and Management Centre for Development, Oxford Department of International Development, University of Oxford, United Kingdom and DST/NRF South African Research Chair in Industrial Development, College of Business and Economics, School of Economics, University of Johannesburg, South Africa; Email: elvis.avenyo@qeh.ox.ac.uk

[‡]DST/NRF South African Research Chair in Industrial Development, College of Business and Economics, University of Johannesburg, South Africa; Email: ftregenna@uj.ac.za

environmentally sustainable industrialisation path for developing countries.

Keywords: carbon dioxide (CO_2) emissions, industrialisation, manufacturing, technology, developing countries

JEL codes: F18, O13, O14, O33, Q01, Q54, Q56

1 Introduction

The manufacturing sector is considered a key engine of growth in the development process, and a source of job creation, livelihoods and, ultimately, social wellbeing (Athukorala & Menon, 1996; Chenery, 1955; Haraguchi, Cheng, & Smeets, 2017; Lall, 1999; Szirmai, 2012; Szirmai, Naudé, & Alcorta, 2013; Tregenna, 2009, 2015, 2016; United Nations Industrial Development Organization [UNIDO], 2016). Industrialisation has been recognised as a key path for developing countries to attain sustained high rates of economic growth and to 'catch up' with advanced economies. Structural change – the shift in the composition of economies from low- to high-productivity activities – is associated specifically with industrialisation. Industrialisation lies at the heart of the economic growth and development literature, especially from a structuralist perspective (Blankenburg, Palma, & Tregenna, 2008).

However, industrialisation is also often associated with environmental degradation in terms of industrial pollution. Industrialisation may evoke an image of 'smokestack industries', with 'dirty' factories releasing dust, smoke, fumes, and toxic gas emissions. Indeed, industrialisation has been identified as one of the main contributors to anthropogenic emissions of CO_2 (Adom, Bekoe, Amuakwa-Mensah, Mensah, & Botchway, 2012; Appiah, Du, Yeboah, & Appiah, 2019; Han & Chatterjee, 1997). This is a key issue for consideration, since climate change is now widely recognised as a central problem facing humanity. The importance of the climate problem, and the urgency with which greenhouse gas (GHG) emissions need to be mitigated, are highlighted in various international responses to climate change. The United Nations Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997), followed by the Doha Agreement (2012) and, more recently, the Paris Agreement (2016), all set out targets for and commitments from both developed and developing countries to reduce GHG emissions by producing and consuming with lower carbon footprints. Anthropogenic emissions of greenhouse gases are generally accepted as the main cause of climate change (Appiah et al., 2019; Friedlingstein et al., 2010; Li & Lin, 2015; Tang & Tan, 2015), with carbon dioxide (CO_2) emissions recognised as the major source of global warming (Balogh & Jámbor, 2017; Friedl & Getzner, 2003).

Industrial development, and the mitigation of emissions, are thus dual goals for many developing countries, but there can be a degree of tension between these two imperatives. Industrialisation can be considered both a route to economic growth and catch-up and as a contributor to climate change. This conundrum is particularly relevant for late industrialisers, since advanced economies did not have to deal with the obligation of reducing emissions during their own earlier phases of industrialisation.

In this paper, we analyse the extent to which harmful CO_2 emissions from manufacturing are conditional on the degree of technology intensity in manufacturing. While recent industrial policies in developing countries target and promote investments in technology-intensive manufacturing industries, there is little empirical understanding of the environmental impact of low-, medium- and high-technology manufacturing industries. We thus compare the extent to which low-, medium- and high-tech manufacturing are CO_2-emitting in developing and emerging economies, considering both the technology intensity of manufacturing value added and exports. The analysis covers 56 developing and emerging countries over the period 1991 to 2014, using a panel dataset constructed from World Bank and UNIDO data and using generalised method of moments (GMM) estimation. We utilise two alternative measures of CO_2 emissions, viz. CO_2 emissions in kilotons and CO_2 emissions in metric tons per capita.

Technology-intensive manufacturing activities generally take place in medium- and high-technology (MHT) industries that typically are reliant on advanced scientific and technological expertise, and high R&D expenditure (Seyoum, 2004) and are often considered 'cleaner' than traditional heavy industries based on processing resources. In this paper, the classification of activities by technology intensity is based on their sectoral classification following the classification of the Organisation for Economic Co-operation and Development (OECD) (2003) (see Table A.1). That is, certain sub-sectors of manufacturing are classified as low-technology (e.g. food products, beverages, and tobacco), others as medium-technology (e.g. electrical machinery and apparatus) and others as high-technology (e.g. pharmaceuticals).

Our baseline empirical results indicate a concave positive relationship between manufacturing value added as a share of GDP and CO_2 emissions. We present two sets of results concerning the effects of technology intensity in manufacturing on emissions. Firstly, in terms of manufacturing value added, medium- and high-tech manufacturing have a convex negative relationship with CO_2 emissions, in contrast with the concave positive relationship between low-tech manufacturing value added and CO_2 emissions. Secondly, for manufacturing exports, where data allows us to separate medium- and high-tech manufacturing, we find a convex negative relationship between both of these and CO_2 emissions, but with medium-tech manufacturing exports associated with higher emissions than high-tech manufacturing exports. In contrast, low-tech manufacturing exports have a convex positive relationship with CO_2 emissions. These findings suggest that technology intensity does matter for CO_2 emissions.

Our primary contribution to the literature is thus in the new evidence for how technology intensity in manufacturing affects CO_2 emissions. The paper makes two secondary contributions to the literature. Firstly, we add to the limited evidence for the relationship between industrial development (specifically manufacturing, rather than industry as a whole) and emissions in developing and emerging economies. Not only are there empirical dimensions specific to developing countries, but this evidence has particular policy implications. Secondly, the paper makes a methodological contribution by adapting and synthesising the environmental Kuznets curve (EKC) and the stochastic impact by regression on population, affluence, and technology (STIRPAT) models, rather than utilising just one of these approaches.

The rest of the paper is structured as follows. The relevant literature is reviewed in Section 2. Section 3 presents our model, estimation methodology, and data. The results are presented in Section 4, while Section 5 discusses the findings and concludes.

2 Literature review

We begin in Section 2.1 by reviewing the broad literature on the effects of industrialisation on climate change, including emerging discourse on the possibilities of a green industrialisation path. Next, in Section 2.2, we discuss empirical studies on country-level determinants of CO_2 emissions, in particular the evidence for industrialisation as a determinant of emissions. In the third part of the literature review, Section 2.3, we consider the key literature on technology intensity, in particular as it relates to industrial development and the mitigation of climate change.

2.1 Industrialisation, industrial policy, and CO_2 emissions

Industrialisation and climate change

There is now a growing body of interdisciplinary literature on the effect of human activities on global warming. While industrialisation is important as a source of sustained increases in productivity and economic growth, it has also been identified as a major driver of anthropogenic emissions (Barca & Bridge, 2015; Zhang, 2012). Evidence associating industrialisation with environmental degradation and carbon emissions has raised concerns about the possibility of achieving sustainable development under paths involving heavy industrialisation.

This literature shows that the stimulating effect of industrialisation on CO_2 emissions occurs mainly at lower stages of industrialisation, and that this effect diminishes at more advanced stages of industrialisation where production and consumption tend to be much cleaner and energy-efficient (the so-called inverted U-shaped relationship) (see, among others, Appiah et al., 2019; Balogh & Jámbor, 2017; Li & Lin, 2015; Liu & Bae, 2018; Timmons Roberts & Grimes, 1997).

Green industrial policy

An emerging approach recognises the dual importance of industrialisation and the need to mitigate emissions (and environmental damage more broadly) (see, for instance, Altenburg & Rodrik, 2017; Rodrik, 2014). Hence, there is a growing push towards industrial development that, while generating productivity growth and jobs, particularly in developing countries, is also environmentally sustainable – the so-called 'dual challenge' (Altenburg & Rodrik, 2017; Fischer, 2016).

Connected to this is the recognition that 'green industrial policy' could foster the transformation of production processes through the use of greener technologies and methods, thereby encouraging sustainable industrialisation pathways (Harrison, Martin, & Nataraj, 2017; Matsuo & Schmidt, 2019; Okereke et al., 2019; Pollin, 2020; Rodrik, 2014). Green industrial policy has been considered an essential tool to reduce greenhouse emissions by compensating for the positive global externalities from green goods and building on the economic opportunities generated by the production and consumption of green technologies (Fischer, 2016).

In the face of pressing development challenges, green industrial policy offers emerging and low-income countries enormous opportunities to industrialise sustainably and to create jobs and economic prosperity (Harrison et al., 2017; Kemp & Never, 2017). Given that environmental losses are global and irreversible beyond a certain limit, and that developing countries are more vulnerable to the immediate effects of climate change, there arguably is a more urgent need for policy aimed at abating the climate problem in developing countries (Padilla, 2017). Understanding how de-carbonising industrialisation through technological progress affects CO_2 emissions may be essential for green industrial policy and sustainable industrialisation pathways.

2.2 Empirical evidence of country-level determinants of CO_2 emissions

Here, we review the existing econometric evidence for the determinants of CO_2 emissions, with particular attention to the effects of industrialisation on emissions. After providing a general overview of econometric approaches, we review bodies of literature that use different econometric methods with a focus on the empirical findings.

Overview of key econometric approaches

From a methodological point of view, two main approaches are widely employed to analyse the determinants of CO_2 emissions: the EKC model/hypothesis (see, for example, Friedl & Getzner, 2003), and the stochastic impact by regression on population, affluence and technology (STIRPAT) method (Dietz & Rosa, 1997). The STIRPAT approach[1] (Dietz & Rosa, 1997), developed on the basis of the impact on population, affluence, and technology (IPAT) method (Ehrlich & Holdren, 1971), is the most widely used approach in the industrialisation-CO_2 emissions literature (Appiah, Du, Musah, & Afriyie, 2017; Li & Lin, 2015; Liu & Bae, 2018; Raheem & Ogebe, 2017; Xu & Lin, 2015, 2017; Yassin & Aralas, 2019; Zhu, Liu, Tian, Wang, & Zhang, 2017).

The STIRPAT method

In an implementation of the STIRPAT method using a non-parametric additive regression model and provincial panel data from China, Xu and Lin (2015)

[1] See Li and Lin (2015) for an overview of the literature applying the STIRPAT model.

find a U-shaped relationship between CO_2 emissions and industrialisation. This suggests that lower levels of industrialisation are associated with lower CO_2 emissions, while higher levels of industrialisation raise CO_2 emissions. Similarly, Liu and Bae (2018), using the autoregressive distributed lag (ARDL) and vector error-correction model (VECM), also find industrialisation (share of industrial value added in GDP) to be positively related to CO_2 emissions in China. Other studies that find similar results in other developing regions include those by Appiah et al. (2019) and Lin, Omoju, and Okonkwo (2015). Using the ARDL approach, Appiah et al. (2019) find that, in the long run, industrialisation increased CO_2 emissions in Uganda.

Related studies have found that the relationship between CO_2 emissions and industrialisation varies across development stages. For example, using different estimation methods, including the dynamic panel threshold panel model, for 73 countries between 1971 and 2010, Li and Lin (2015) find that industrialisation, measured as the ratio of secondary to primary industry, has different effects on CO_2 emissions at different stages of economic development. The results of Poumanyvong and Kaneko (2010), based on pooled data for 99 countries, corroborate Li and Lin's (2015) finding that the development stage matters in the relationship between CO_2 emissions and industrialisation. Analysing the relationship between CO_2, urbanisation, and industrialisation for 20 African economies, Raheem and Ogebe (2016) find that, in the long run, industrialisation leads to lower CO_2 emissions through the income mechanism. That is, as countries become wealthier, they pollute less and clean better through extensive investment in efficient production and consumption systems.

The EKC approach

The EKC hypothesis strand of the literature mainly examines the relationship between CO_2 emissions and countries' levels of economic development (typically measured in GDP per capita and its square), alongside other explanatory variables. Generally, the results from this body of literature point to an inverted-U relationship between economic development and CO_2 emissions. This suggests that, as a stylised fact, levels of CO_2 emissions generally rise as countries become more developed, but this is at decreasing rates and they even level off and decline at higher levels of economic development (Adom et al., 2012; Balogh & Jámbor, 2017; De Souza, Freire, & Pires, 2018; Friedl & Getzner, 2003; Xu & Lin, 2015).

Testing the industrialisation-CO_2 emissions nexus with the EKC model using GMM and 24-year panel data from 168 countries, Balogh and Jámbor (2017) find an inverted-U relationship between industry as a share of countries' GDP and CO_2 emissions. This evidence is supported by other empirical studies. Using time-series data for Ghana, Senegal, and Morocco from 1971 to 2007, Adom et al. (2012) find a positive relationship between industrial structure and CO_2 emissions across all three countries. Xu and Lin (2015) also confirm the EKC hypothesis for the case of China.

Analysis of the tertiarisation effect

Some studies decompose the structure of the economy, from agriculture to manufacturing and service sectors, to determine their different impacts on CO_2

emissions (see, for example, Kijima, Nishide, & Ohyama, 2010). The main theoretical argument is that the shrinking of the share of the manufacturing sector, and the concomitant expansion of the service sector (tertiarisation), will lead to a reduction in carbon emissions (Marsiglio, Ansuategi, & Gallastegui, 2016; Minx et al., 2011).

Several empirical studies confirm the tertiarisation effect in lowering CO_2 emissions. Using the STIRPAT analytical framework and dynamic common correlated effects (DCCE) estimation method, Yassin and Aralas (2019) examine the relationship between deindustrialisation, tertiarisation, and CO_2 emissions in Asian countries for the period 2012 to 2015, finding that deindustrialisation reduces CO_2 emissions. This result is in line with Zhang, Liu, Zhang, and Tan (2014) and Zhu et al. (2017), who find that structural change in the sense of the relative growth of the services (tertiary) sector curbs CO_2 emissions. In contrast, Friedl and Getzner (2003) find that tertiarisation of the Austrian economy has had negative but insignificant effects on CO_2 emissions.

Concluding remarks on econometric approaches

Overall, there is extensive literature that tests both the EKC and STIRPAT models. However, both strands of the literature analyse the effect of industrialisation on CO_2 emissions only partially and do not control for all key variables.

In the first step in our empirical analysis, we adapt both the EKC and STIRPAT models to examine the relationship between industrialisation and CO_2 emissions in developing economies. In doing so, we use a modified form combining insights from both the EKC and STIRPAT strands of the literature, and with the inclusion of additional covariates.

Furthermore, we examine the specific effect of manufacturing activity disaggregated by technology intensity on emissions, instead of using industry value added as a percentage of GDP (see, for example, Balogh & Jámbor, 2017; Liu & Bae, 2017; Xu & Lin, 2015) and/or industrial structure (see, for example, Adom et al., 2012). While the available proxies of industrial activity are informative, industry value added as a percentage of GDP, for instance, is an imprecise measure as it also includes mining, construction, and utilities. Our proxies of industrial activity disaggregated by technology intensity provide a more granular understanding of the effect of manufacturing on CO_2 emissions.

2.3 Technology intensity

The importance of technology intensity and technological upgrading

Technological progress is at the core of industrialisation (Lall, 1992; Rodrik, 2014; Zhang, 2012). Technological upgrading, and in particular the transition from low- to medium- and high-technology manufacturing, is seen as important for developing countries to enhance their competitiveness, develop their capabilities in products for which there is relative growth in global demand, and attain sustained structural transformation and economic growth (see, for example, UNIDO, 2016). ‘Keeping pace’ with technological change and innovation is important for countries to avoid a ‘middle-income technology trap’, and a middle-income trap more broadly (Andreoni & Tregenna, 2020).

Medium- and high-tech (MHT) manufacturing industries are often at the frontier of technological progress and represent a source of spillover effects and linkages. MHT manufacturing industries produce complex products that have been identified as 'growth catalysts', particularly through the enhancement of industrial competitiveness, technological deepening and upgrading, investment in research and development (R&D), and innovation activities (Hobday, 2013). These features have the potential to boost economic performance in the broader economy through backward and forward linkages to other sectors, as well as associated positive externalities.

Technology-intensive manufacturing therefore has important implications for a country's industrial value creation and addition, product diversification and sophistication, and the pushing of a country's technological frontier. Moreover, there is extensive evidence that high-technology-intensive ?rms are typically more innovative, more ef?cient, pay higher wages, and are more successful than low-technology-intensive ?rms (Hatzigeorgiou, Polatidis, & Haralambopoulos, 2011; Montobbio & Rampa, 2005). MHT exports also tend to have higher competitive power in international commerce through efficiency in production and resource distribution, leading to an increase in market size (associated with ease of entry into new markets) and an increase in foreign investment (Fuchs & Kirchain, 2010; Pisano & Shih, 2012; Tassey, 2010). Furthermore, MHT manufacturing industries do not follow the same path of deindustrialisation as do low-tech manufacturing industries (Tregenna & Andreoni, 2020). Thus, enhancing the technological content of exports has been recognised as important in the industrialisation strategies and industrial policies of developing countries (UNIDO, 2005).

Technology intensity and the green transition

Of particular relevance here is the role of MHT manufacturing industries in de-carbonising industrialisation. MHT are generally characterised by advanced scientific and technological expertise and high R&D expenditure (Seyoum, 2004) that could stimulate and enable the global economy to produce and consume sustainably. With an understanding that technology-intensive manufacturing is central to the aspirations of the green economy and has the potential to drive sustainable economic prosperity, industrial policies in developing countries are increasingly being re-oriented towards the promotion of technology-intensive machinery and the sustainable production of complex and sophisticated products.

Developing countries may be able to de-carbonise industrialisation and grow sustainably through green technological progress (Altenburg & Assmann, 2017; Altenburg & Rodrik, 2017; Harrison et al., 2017; Nakicenovic, Kolp, Riahi, Kainuma, & Hanaoka, 2006; Zhang, 2012). Green technologies are relevant for sustainable economic growth paths (Pasche, 2002; Rodrik, 2014).

MHT manufacturing industries therefore have the potential to drive low-carbon industrialisation pathways in developing economies. MHT industries generally may be greener and could be associated with lower CO_2 emissions compared to low-tech manufacturing. Furthermore, high-technology-intensive manufacturing industries are expected to be less polluting than medium-technology-intensive manufacturing industries.

However, there is little empirical evidence concerning the relationship between the technology intensity of manufacturing industries and their effect on CO_2 emissions, especially in developing economies. Our paper makes a key contribution to the literature by estimating and comparing the extent to which low-, medium- and high-tech manufacturing are CO_2-emitting in developing and emerging economies, considering the technology intensity of both manufacturing value added and exports.

3 Methodology and data

3.1 Empirical strategy

Model and specifications

In this section, we present and discuss the empirical method and data employed in this paper. As noted, our empirical model is a modification of the EKC and STIRPAT models. The adaption of these models commonly used in the existing literature on growth, industrialisation, and emissions enables us to uniquely introduce and examine key variables. These are both the covariates (such as fossil fuel energy consumption and the relative size of the service sector) and, more importantly, our main variables of interest (low-tech and combined medium- and high-tech shares in manufacturing value added, and low-, medium- and high-tech shares in manufacturing exports).

Following Balogh and Jámbor (2017), Friedl and Getzner (2003), and Xu and Lin (2015), we specify our general empirical model as:

$$lnCO_{2it} = f(lnCO_{2it-1},\, lnGDP_{it},\, MAN_{it},\, Z_{it}) \tag{1}$$

Based on the general model in equation (1), our basic model is specified as:

$$\begin{aligned} lnCO_{2it} \;=\;& \gamma_1+\gamma_2 lnCO_{2it-1}+\gamma_3 lnGDP_{it}+\gamma_4 lnGDP_{it}^2+\gamma_5 MAN_{it} \\ &+\gamma_6 MAN_{it}^2+\gamma_7 Z_{it}+\varepsilon_{it}, \end{aligned} \tag{2}$$

where $lnCO_{2it}$ refers to CO_2 emissions in country i in year t, while $lnCO_{2it-1}$ captures its lag, both in natural logarithm. Two main measures of CO_2 emissions are used in the empirical literature: CO_2 emissions per capita (Balogh & Jámbor, 2017; De Souza et al., 2018; Liu & Bae, 2017; Raheem & Ogebe, 2016; Xu & Lin, 2015) and total CO_2 emissions (Friedl & Getzner, 2003). Both of these measures of emissions are relevant in different ways – analytically and for policy – and we present estimation results for both, which also helps to test the robustness of our results. ε_{it} is a standard error term.

In our extended models that investigate the effects of technology intensity in manufacturing on CO_2 emissions, we replace the overall manufacturing variables (in linear and quadratic form) in our baseline specification with the shares of different categories of manufacturing by technology intensity. Firstly, for the composition of manufacturing value added, we compare low-tech manufacturing with combined medium- and high-tech manufacturing. These are formulated as:

$$
\begin{aligned}
lnCO_{2it} &= \gamma_8 + \gamma_9 lnCO_{2it-1} + \gamma_{10} lnGDP_{it} + \gamma_{11} lnGDP^2_{it} + \gamma_{12} MHTM_{it} \\
&\quad + \gamma_{13} MHT^2_{it} + \gamma_{14} Z_{it} + u_{1it} \qquad \text{(3i)}
\end{aligned}
$$

$$
\begin{aligned}
lnCO_{2it} &= \gamma_{15} + \gamma_{16} lnCO_{2it-1} + \gamma_{17} lnGDP_{it} + \gamma_{18} lnGDP^2_{it} + \gamma_{19} LTM_{it} \\
&\quad + \gamma_{20} LT^2_{it} + \gamma_{21} Z_{it} + u_{2it} \qquad \text{(3ii)}
\end{aligned}
$$

Secondly, for the composition of manufacturing exports, the data allows us to separately estimate and compare low-, medium- and high-tech manufacturing.

$$
\begin{aligned}
lnCO_{2it} &= \gamma_{22} + \gamma_{23} lnCO_{2it-1} + \gamma_{24} lnGDP_{it} + \gamma_{25} lnGDP^2_{it} + \gamma_{26} LTE_{it} \\
&\quad + \gamma_{27} LT^2_{it} + \gamma_{28} Z_{it} + u_{3it} \qquad \text{(4i)}
\end{aligned}
$$

$$
\begin{aligned}
lnCO_{2it} &= \gamma_{29} + \gamma_{30} lnCO_{2it-1} + \gamma_{31} lnGDP_{it} + \gamma_{32} lnGDP^2_{it} + \gamma_{33} MTE_{it} \\
&\quad + \gamma_{34} MT^2_{it} + \gamma_{35} Z_{it} + u_{4it} \qquad \text{(4ii)}
\end{aligned}
$$

$$
\begin{aligned}
lnCO_{2it} &= \gamma_{36} + \gamma_{37} lnCO_{2it-1} + \gamma_{38} lnGDP_{it} + \gamma_{39} lnGDP^2_{it} + \gamma_{40} HTE_{it} \\
&\quad + \gamma_{41} HT^2_{it} + \gamma_{42} Z_{it} + u_{5it}, \qquad \text{(4iii)}
\end{aligned}
$$

where $MHTM$ and LTM refer to medium-high-technology manufacturing and low-technology manufacturing in country i in year t, respectively. LTE, MTE and HTE represent low-, medium- and high-technology exports in country i in year t, respectively. $u_{1it}...u_{5it}$ are the standard, independently distributed error terms.

$lnGDP_{it}$ and $lnGDP^2_{it}$ measure the log of GDP per capita in constant 2011 US$ and its squared term in country i in year t, respectively, in line with both the EKC (see, for instance, Friedl & Getzner, 2003) and the STIRPAT (see, for instance, Xu & Lin, 2015) models. MAN_{it} refers to manufacturing value added as a percentage of GDP in country i in year t.

Z_{it} is a vector of other exogenous variables identified from the EKC and STIRPAT literature, as listed in Table 1. Energy use is considered a major driver of CO_2 emissions (Xu & Lin, 2015), and the use of renewable energy sources is recognised as a critical avenue to reduce emissions sustainably (Liu & Bae, 2017). We include renewable energy consumption (De Souza et al., 2018; Liu & Bae, 2017) and fossil fuel energy consumption (De Souza et al., 2018) to capture the separate effects of renewable energy and fossil fuel energy consumption on emissions. We expect lower use of renewable energy and higher fossil fuel energy consumption to be associated with higher CO_2 emissions.

Developing countries are typically characterised by rapid urbanisation (Li & Lin, 2015). The rapid growth of cities leads to the rapid growth of transport systems, the construction of drainage systems, and changes in land use, leading to environmental pollution and higher CO_2 emissions. In other words, urban areas are 'emission-intensive', as argued by Xu and Lin (2015). We therefore control for urbanisation (De Souza et al., 2018; Liu & Bae, 2017; Xu & Lin, 2015), expecting a positive relationship between urbanisation and emissions.

The service sector accounts for the largest share of GDP in most developing countries. Services activities are generally less energy-intensive than industry. We control for the share of service sector value added as a share of GDP to measure the tertiarisation of the economy (Yassin & Aralas, 2019). It is expected that a shift from industrial activity to service-based activities will lead to lower emissions.

We further introduce a proxy for trade (trade percentage of GDP) to capture openness (Balogh & Jámbor, 2017; Bento, 2014; De Souza et al., 2018). The global opening up of trade has led to increasing pressure to meet international standards, particularly on goods coming from developing countries. We expect higher trade openness to lead to higher adherence to international climate protocols, thereby leading to lower CO_2 emissions, in line with De Souza et al. (2018).

Finally, we include a covariate for domestic credit as an indicator of countries' levels of financial development (De Souza et al., 2018). While the effects on emissions are likely to be ambiguous, more developed financial sectors and greater financial depth could provide easier access to cheaper private credit and loans, which may lead to greener energy use and lifestyles. ε_{it} is the idiosyncratic error term.

Estimation

To estimate our models, we utilise Arellano and Bond's (1991) dynamic panel data estimation method, using the two-step GMM estimator to enhance the precision of the estimates and also to reduce the bias identified in finite panels with a short time period (T) and large N (Blundell & Bond, 1998; Blundell, Bond, & Windmeijer, 2000). Biased two-step GMM standard errors are corrected for by reporting Windmeijer (2005) robust standard errors. We also report the order autoregression to test the serial correlation between error terms.

Given the existing evidence suggesting that economic development has a non-linear relationship with CO_2 emissions, we include quadratic terms in our basic and extended models to explore the non-linearity of the relationships between our manufacturing variables and emissions.

3.2 Data

Table 1 presents the descriptive statistics and data sources of our key variables. The dataset employed for the analysis in this paper is built from two main sources. All data, apart from that on the disaggregation of manufacturing value added by technology intensity, was sourced from the World Bank's World Development Indicators (WDI).[2]

Data on manufacturing value added by level of technology intensity (the variables 'Medium- and high-tech VA' and 'Low-tech VA') was obtained from

[2] https://datacatalog.worldbank.org/dataset/world-development-indicators

the United Nations Industrial Development Organization (UNIDO) Competitive Industrial Performance (CIP) database.[3] This database classi?es manufacturing sectors into four technology levels – low, medium-low, medium-high and high – following the OECD (2003). These levels are consolidated here into three categories: low-, medium-, and high-technology. See Table A.1 in the Appendix for the OECD classification of industries according to their degree of technology intensity.[4] This categorisation of manufacturing by technology intensity is based on the sectors of manufacturing, as set out in Table A.1. As such, no composite measure of the technology intensity of manufacturing as a whole is used here. Rather, we separately analyse the association between different categories of manufacturing by technology intensity, and CO_2 emissions.

The UNIDO CIP covers 150 countries over the period 1990 to 2016. This serves as the parent database to determine the number of countries and periods in our analysis. That is, the length of our panel is based primarily on the availability of data, with variables such as renewable energy consumption available only from 1990. Furthermore, we dropped countries with very short periods of data coverage.

Our final dataset covers 56 developing and emerging economies (listed in Table A.2 in the Appendix) over the period 1991 to 2014. Country selection is based on the IMF classification of 'emerging and developing countries' and 'low-income developing countries', and data availability. Geographically, our final country sample includes 13 countries from Africa, 16 from Latin America and the Caribbean, eight from Eastern Europe and Central Asia, and 18 from Asia (excluding Central Asia). By levels of industrialisation based on the UNIDO classification (Upadhyaya, 2013), we have two industrialised countries, 21 emerging industrial economies (EIEs), 24 other developing countries (ODEs), and nine least developed countries (LDCs). On average, our sample countries generated about 237 494 kilotons (kt) of CO_2 emissions in the period under review. In per capita terms, our data shows that the developing countries in our sample generated about 2.9 metric tonnes (mt) of CO_2 emissions per capita, with values ranging between 0.017 and 19.529.

In terms of MHT indicators, the data for our sample shows that, on average, about 22% of total manufacturing value added comes from medium- and high-tech industries, which is lower than that of advanced industrialised nations such as the United States of America (USA) (49%) and Germany (62%) in 2014. Similarly, exports of medium- and high-tech manufacturing account for about 28% of total manufactured exports for our sample countries on average, significantly less than in industrialised countries such as the USA (62%) and Germany (73%) in 2014. This shows that MHT industries are less developed

[3] https://stat.unido.org/cip/

[4] It is important to recognise that there is considerable heterogeneity in technology intensity *within* each of the categories of low-, medium- and high-tech manufacturing. For instance, some activities within 'food products, beverages and tobacco' (which is classified as a low-tech sector of manufacturing) are more technology intensive than some activities within 'chemicals excluding pharmaceuticals' (classified as medium-tech). See Lall (2000) and Pavitt (1984) for other commonly used technology classifications in the literature.

and play a less significant role among our sampled countries; the industrial structure of the developing countries under consideration is dominated largely by low-technology industries.

For other key explanatory variables, our data shows that about 37% of total energy consumption on average comes from renewable energy for our country sample, while the remaining 63% comes from fossil fuels. Fossil fuels therefore dominate the energy mix of the sampled developing countries. On average, the service sector contributes about half of total value added. Our data also shows that about 24% of the total population in the sampled countries lives in urban areas.

Figure 1 shows the evolution of CO_2 emissions (using both our measures of emissions) over time for selected countries in our sample. China produces by far the largest absolute volume of emissions (Figure 1a) as a function of its large population size and high levels of emissions-intensive production. India overtook Russia as the second-highest emitter in absolute volumes, followed by South Africa and Brazil, with very low volumes from the other countries depicted here. A different picture emerges for CO_2 emissions per capita (Figure 1b), with China ranked third (following Russia and South Africa) for the countries shown here, having overtaken Argentina by 2005. As would be expected, low- and lower-middle-income countries (Ethiopia, Nigeria, India, and Vietnam) have the lowest emissions per capita of those presented here.

4 Results

First, we present baseline estimations of the overall effects of manufacturing on CO_2 emissions, using both linear and quadratic specifications (Table 2). Second, we examine the relationship between technology intensity in manufacturing value added and CO_2 emissions, comparing combined medium- and high-tech manufacturing with low-tech manufacturing (shares in total manufacturing value added) (Table 3). Third, we analyse the relationship between technology intensity in manufacturing exports and CO_2 emissions; here, the data allows us to separately compare high-, medium- and low-tech manufacturing (shares in total manufacturing exports) (Table 4). These second and third sets of results shed light on our central research question: how does technology intensity in manufacturing affect the relationship between industrialisation and CO_2 emissions?

All regressions are run with the same set of covariates and for a uniform sample of developing countries (as discussed in Section 3; see also Table A.2 in the Appendix for the full sample country list), using the Arellano and Bond (1991) dynamic panel two-step GMM estimator. In all cases, results are presented using both our measures of CO_2 emissions as alternative dependent variables.

4.1 Baseline estimations: effect of manufacturing on CO_2 emissions

Table 2 shows the estimation results from our basic model where we regress CO_2 emissions on manufacturing value added (% of GDP) and relevant covariates. Columns 1 and 3 present the linear models, while columns 2 and 4 show the results for the quadratic models, which are our preferred specifications. Results are shown for both measures of CO_2 emissions: in kilotons (columns 1 and 2) and in metric tons per capita (columns 3 and 4).

The share of manufacturing in total value added ('Manufacturing VA') has a significant positive effect on CO_2 emissions (kilotons) (column 1), with the coefficient becoming larger and even more significant in the quadratic specification (column 2). The square of manufacturing value added is negative and statistically significant. This indicates a concave positive relationship between CO_2 emissions (measured in kilotons) and manufacturing value added (% of GDP). This is consistent with the results of scholars such as Balogh and Jámbor (2017), De Souza et al. (2018), Friedl and Getzner (2003), and Xu and Lin (2015).

The overall positive relationship between the share of manufacturing in GDP and CO_2 emissions is as expected, and confirms that industrialisation is associated with higher emissions. The non-linearity in this relationship indicates that emissions fall at a decreasing rate with more industrialisation. This flattening out of the curve may be due to efficiency gains as a result of investment in energy-saving technologies and production processes, energy-saving transport systems, and strict environmental policies at advanced stages of manufacturing, thereby mitigating CO_2 emissions. These emissions-mitigating innovations may be uneconomical in the early stages of industrialisation, leading to the use of old technologies in the production of energy-intensive products that generate higher levels of CO_2 emissions. Using CO_2 emissions measured in metric tons per capita as the dependent variable, the signs of the estimated coefficients are the same as with CO_2 emissions in kilotons, but are no longer statistically significant; we explore this further in our extended models.

CO_2 emissions are found to be path dependent, with lagged CO_2 emissions having a significant positive effect on current CO_2 emissions (see all columns in Table 2). The results regarding covariates are consistent with the existing literature. The estimation results from the quadratic models (columns 2 and 4 of Table 2) show an inverted-U relationship between CO_2 emissions and GDP per capita. Even though our sample is of developing countries, this result is consistent with the EKC hypothesis literature, which finds that countries in the early stages of development tend to have higher CO_2 emissions, but these high emission levels eventually fall at higher levels of development (Balogh & Jámbor, 2017; De Souza et al., 2018; Xu & Lin, 2015). This finding may be due to the fact that our study analyses developing countries. Our estimation results reported across all columns of Table 2 indicate that services value added as a percentage of GDP has a significantly negative effect on CO_2 emissions. This confirms the 'tertiarisation effect' hypothesis, namely that an increasing share of services in GDP mitigates CO_2 emissions, in line with Yassin and Aralas (2019) and other studies. This may be because the service sector is less energy intensive than are the primary and secondary sectors.

Further, we find that the higher the share of fossil fuel energy consumption in a country's total energy mix, the higher the CO_2 emissions, in line with De Souza et al. (2018). Our results from the baseline regressions suggest that renewable energy consumption as a percentage of final energy consumption has a negative but mostly insignificant effect on CO_2 emissions in the countries under study. While perhaps surprising, this may due to the small to negligible share of renewable energy consumption on average (about 37%) in the total energy mix of our country sample. As a result, the clean effect of renewable energy may not yet be translating directly into a reduction in CO_2 emissions in our sampled developing countries. A similar study on China by Liu and Bae (2017) also found renewable energy to have no significant effect on CO_2 emissions.

While domestic credit provided by the financial sector as a percentage of GDP is found to have the expected sign, it is only significant in the case of CO_2 emissions (kilotons), suggesting that developing countries with a developed financial sector produce less CO_2 emissions per kiloton. Trade and urbanisation are insignificant across the different specifications in our baseline regressions.

4.2 Effect of technology intensity in manufacturing on CO_2 emissions

Next, we explore how technology intensity in manufacturing affects CO_2 emissions in developing countries. In this, we first consider the relationship between the technology intensity of manufacturing value added and CO_2 emissions. We separately analyse the effects of the share of low-tech manufacturing in total manufacturing value added, and the combined share of medium- and high-tech manufacturing in total manufacturing value added, on CO_2 emissions. Second, we focus on how the technology intensity of manufacturing exports affects CO_2 emissions. In this respect, the data allows us to separately analyse the effects of low-, medium- and high-tech manufacturing exports on CO_2 emissions.

Table 3 shows our results for the technology intensity of manufacturing value added. The results for combined medium- and high-tech manufacturing ('Medium- and high-tech VA') in columns 1 and 2 can be compared with those for low-tech manufacturing ('Low-tech VA') in columns 3 and 4. Again, we use two alternative measures of emissions as dependent variables: kilotons (columns 1 and 3) and metric tons per capita (columns 2 and 4).

The results are generally consistent across all specifications. Medium- and high-tech manufacturing have a significant negative coefficient on the linear term and a significant positive coefficient on the quadratic term for both measures of emissions. This suggests a convex negative relationship. That is, a rising share of MHT in manufacturing value added is associated with falling emissions, flattening out at higher shares of MHT in total manufacturing. In sharp contrast, the share of low-technology value added in manufacturing has a significant positive effect on CO_2 emissions (columns 3 and 4), with this positive effect diminishing at higher shares of low-tech in manufacturing value added (i.e., a concave positive relationship). These differences can be understood in terms of the types of activities classified within each of low-, medium- and high-tech manufacturing (see Table A.1), which vary considerably in how polluting they are.

These results indicate that technology intensity in manufacturing does matter for CO_2 emissions. Whereas higher shares of low-tech manufacturing are associated with higher (at a diminishing rate) emissions, higher shares of medium- and high-tech manufacturing are associated with lower (at a diminishing rate) emissions. Importantly, this implies that technology intensity in manufacturing in developing countries is associated with lower CO_2 emissions.

The results for the covariates are generally consistent with our baseline regressions, but stronger here. In particular, renewable energy, trade, domestic credit, and urbanisation are now generally significant across specifications in Table 3, as well as having the expected signs.

Next, we focus on the effect of technology intensity in manufacturing *exports* on CO_2 emissions. Table 4 compares the results for the shares of high-tech (columns 1 and 2), medium-tech (columns 3 and 4) and low-tech (columns 5 and 6) manufacturing exports in total manufacturing exports. As previously, these are shown for both measures of CO_2 emissions as alternative dependent variables.

Again, our results show technology intensity in manufacturing to be associated with lower CO_2 emissions. The patterns are even clearer here, as we are able to run separate regressions for medium- and high-tech manufacturing in the case of exports and compare both to low-tech manufacturing. For low-tech manufacturing exports, both the linear and squared terms are positive (columns 5 and 6 of Table 4), indicating that higher shares of low-tech manufacturing in total manufacturing exports are associated with higher emissions, and at an increasing rate (convex positive). In direct contrast, for both high-tech (columns 1 and 2) and medium-tech (columns 3 and 4) manufacturing exports, the linear coefficient is negative and the quadratic coefficient is positive (convex negative), consistent with the results for manufacturing value added in Table 3.

Of additional interest here is the difference between high- and medium-tech manufacturing exports: high-tech manufacturing is associated with lower emissions than is medium-tech manufacturing. This underscores that emissions are conditional on technology intensity in manufacturing across all categories of technology intensity. This is intuitive when comparing the types of industries classified as high-tech (e.g. ‘medical, precision and optical instruments’ and ‘electronics components’) with those classified as medium-tech (e.g. ‘rubber and plastics products’ and ‘basic metals and fabricated metal products’). A greater orientation to exporting sophisticated and advanced technology-intensive manufactures is more environmentally friendly and leads to lower levels of pollution.

We ran two sets of supplementary regressions as robustness checks. Firstly, we re-estimated all regressions using fixed and random effects. Secondly, we re-estimated all ten of our regressions concerned with the technology intensity of manufacturing (as presented in Tables 3 and 4) with the shares of manufacturing technology categories in GDP and in total exports. That is, we ran robustness checks for the estimations in Table 3, with the explanatory variables of interest as the shares of medium- and high-tech manufacturing value added in GDP (instead of in total manufacturing value added). For the estimations in Table 4, our robustness check had each of the shares of medium- and high-tech manufacturing exports in *total* exports (instead of in total manufacturing exports) as the explanatory variables of interest. All these robustness checks yielded results that are broadly consistent with and supportive of our main results.[5]

5 Discussion and conclusions

In developing countries, there is growing recognition of the need to re-orient industrial production processes and structures towards technology-based manufacturing industries and to accelerate their technological upgrading in order to add value and produce 'complex' products, but also to integrate into and benefit from global value chains, international trade, and rapid globalisation.

Beyond the importance of technological upgrading for industrial development and growth, could it also be relevant in mitigating CO_2 emissions from manufacturing? While there is an established body of evidence showing a positive relationship between industrialisation and emissions, there is a dearth of evidence for how this relationship may be conditional on technology intensity in manufacturing. In an era of rapid technological development, along with the urgent need for sustainable modes of production, it becomes particularly important to explore the nexus between technology intensity, industrialisation, and CO_2 emissions. This is of particular interest to developing economies as they strive to catch up and to improve the well-being of their citizenry. In this study, we consider the technology intensity of manufacturing in terms of the OECD (2003) classification of sub-sectors of manufacturing into the categories of low, medium or high technology.

Using the GMM two-step estimator, we undertook an analysis of 56 developing countries between 1991 and 2014. Our baseline results confirm a concave positive relationship between manufacturing value added and CO_2 emissions (kt). The non-linearity of this relationship indicates that the positive relationship between industrialisation and emissions diminishes at higher levels of industrialisation.

One way in which our analysis contributes to the broad empirical literature on the relationship between industrialisation and CO_2 emissions is by analysing manufacturing specifically (instead of industry in general, which includes mining, construction, and utilities). We also add to the limited literature on developing and emerging economies; this is especially important in the light of the challenges of late industrialisation in the context of the need to mitigate climate change. We also make a methodological contribution by adapting and

[5] Results from the robustness tests are not shown for reasons of space, but are available from the authors on request.

synthesising the EKC and STIRPAT methodological approaches, whereas the extant literature employs only one or the other of these models.

Our primary contribution lies in the new evidence presented here regarding the relationship between the technology intensity of manufacturing and CO_2 emissions in developing countries. This is important, as emissions vary considerably across different sub-sectors of manufacturing. In our analysis of manufacturing value added by technology intensity, we find a convex negative relationship between medium- and high-tech manufacturing and CO_2 emissions, in contrast to our results for manufacturing as a whole and for low-tech manufacturing. These differences are even clearer in our results for manufacturing exports, where we can compare low-, medium- and high-tech manufacturing exports. The convex positive effect of low-technology manufacturing exports on CO_2 emissions may be explained in terms of the pollution haven hypothesis, where developing countries serve as the world's factory for the production of low-tech, dirty, and pollution-enhancing primary and intermediate products. High-technology manufacturing exports generate less CO_2 emissions compared with medium-technology manufacturing exports. The convex negative relationship, for both of these categories, may be explained by structural change, that is, the trade-off between the tertiarisation and in/deindustrialisation of the economy.

These striking findings can be understood in terms of the differences between MHT manufacturing and the rest of manufacturing, both in terms of what is produced and how it is produced. MHT manufacturing generally tends to be cleaner than low-tech manufacturing. Activities within low-tech manufacturing, such as pulp and paper production, and within medium-low-technology manufacturing, such as rubber and plastics production, are far more polluting per unit of value added than are high-technology manufacturing activities, such as the manufacture of medical, precision, and optical instruments. This relates in part to the intrinsic characteristics of production in such industries, which for most of the MHT sectors are not based on chemical processes. Furthermore, the typically high value-to-volume ratio of MHT activities (relative to low-tech manufacturing) implies that they are likely to be less polluting per unit of value added, and also that the adoption of cleaner technologies is more likely to be economically viable for producers.[6]

Based on the results of covariates across our regressions, we find support for the EKC hypothesis of an inverted-U relationship between economic development and CO_2 emissions. Our results also suggest that services value added as a percentage of GDP and renewable energy consumption lead to lower CO_2 emissions, while increases in fossil fuel energy consumption lead to higher CO_2 emissions.

These findings have important policy implications, in particular at the nexus

[6] As noted earlier, categories of manufacturing by technology intensity are based on sectors within manufacturing, and not on the degree of technological advancement in particular processes and products. Despite these categories being broad, with considerable variation in the degree of technology intensity within each, the differences in emissions by category are pronounced.

of industrial, technological, and environmental policies in developing countries. Shifting to more technology-intensive industries may be one way for developing countries to navigate the dual challenges of industrialisation and mitigating climate change. This suggests that developing countries need to design industrial strategies that target sector-specific 'cleaner' MHT industries that are able to generate rapid and sustainable economic growth.

The advantages of upgrading to higher-technology manufacturing are already well established for growth and catch-up. Our analysis also underscores the importance of moving towards more technology-intensive manufacturing in terms of environmental sustainability. This suggests that an industrialisation path need not be an environmentally destructive one: a shift to higher-technology industrialisation can provide a development trajectory that is both environmentally sustainable and can provide a basis for high growth and catch-up.

Our results are not intended to suggest that more technology-intensive manufacturing does not contribute to harmful CO_2 emissions, or that a more technology-intensive industrialisation path is the 'silver bullet' for addressing the challenge of climate change. Rather, we draw attention to the differences in emissions between low-, medium- and high-tech manufacturing, suggesting that more technology-intensive manufacturing is less emissions intensive.

Of course, technological upgrading and a shift towards higher-technology manufacturing are, in practice, not straightforward for developing countries. They require, among other things, significant effort and investment in human capital and in upgrading productive capabilities. Even then, firms or countries pursuing technological upgrading face various constraints, including barriers to entry, domestic and international political economy factors, inadequate skills, limited domestic markets for high-tech manufactures, and so on. For low-income countries in particular, rapid technological upgrading is especially challenging; a rapid shift to high-technology manufacturing may not be feasible in the short term, nor may it generate large-scale employment opportunities for low- or semi-skilled workers.

This study opens several avenues for future research. Data limitations precluded us from disaggregating MHT manufacturing value added to examine medium- and high-technology shares separately, as was possible for exports. More disaggregated data for value added would shed additional light on the relationship between technology intensity in manufacturing and emissions. Secondly, a sub-sectoral analysis, in which specific manufacturing industries are examined separately, could also be interesting, especially taking into account the degree of heterogeneity within each of the categories of manufacturing by technology intensity. Thirdly, further research could investigate the channels through which technology intensity affects the manufacturing-emissions relationship, including through more micro-level analysis.

References

[1] Adom, P. K., Bekoe, W., Amuakwa-Mensah, F., Mensah, J. T., & Botchway, E. (2012). Carbon dioxide emissions, economic growth, industrial structure, and technical efficiency: Empirical evidence from Ghana, Senegal, and Morocco on the causal dynamics. *Energy, 47*(1), 314-325.

[2] Altenburg, T., & Assmann, C. (eds.). (2017). *Green industrial policy. Concept, policies, country experiences.* Geneva & Bonn: UN Environment; German Development Institute/Deutsches Institut für Entwicklungspolitik (DIE).

[3] Altenburg, T., & Rodrik, D. (2017). Green industrial policy: Accelerating structural change towards wealthy green economies. In T. Altenburg & C. Assmann (Eds.), *Green industrial policy: Concepts, policies, country experiences* (pp. 2-20). Geneva, Bonn: UN Environment; German Development Institute/Deutsches Institut für Entwicklungspolitik (DIE).

[4] Andreoni, A., & Tregenna, F. (2020). Escaping the middle-income technology trap: A comparative analysis of industrial policies in China, Brazil and South Africa. *Structural Change and Economic Dynamics, 54*, 324-340.

[5] Appiah, K., Du, J., Musah, A. A. I., & Afriyie, S. (2017). Investigation of the relationship between economic growth and carbon dioxide (CO_2) emissions as economic structure changes: Evidence from Ghana. *Resources and Environment, 7*(6), 160-167.

[6] Appiah, K., Du, J., Yeboah, M., & Appiah, R. (2019). Causal relationship between industrialization, energy intensity, economic growth and carbon dioxide emissions: Recent evidence from Uganda. *International Journal of Energy Economics and Policy, 9*(1), 237-245.

[7] Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies, 58*(1), 277-297.

[8] Athukorala, P., & Menon, J. (1996). Foreign investment and industrialization in Malaysia: Exports, employment and spillovers. *Asian Economic Journal, 10*(1), 29-44.

[9] Balogh, J. M., & Jámbor, A. (2017). Determinants of CO_2 emission: A global evidence. *International Journal of Energy Economics and Policy, 7*(5), 217-226.

[10] Barca, S., & Bridge, G. (2015). Industrialisation and environmental change. In T. Perreault, G. Bridge, & J. A. McCarthy (Eds.), *The Routledge handbook of political ecology* (pp. 366-377). Oxon: Routledge.

[11] Bento, J. P. C. (2014). The determinants of CO_2 emissions: Empirical evidence from Italy. Munich Personal RePEc Archive Paper Number 59166. Retrieved from http://mpra.ub.uni-muenchen.de/59166/

[12] Blankenburg, S., Palma, G., & Tregenna, F. (2008). Structuralism. In L. Blume & S. Durlauf (Eds.), *The new Palgrave: A dictionary of economics* (2^{nd} ed., pp. 69-74). Basingstoke: Palgrave Macmillan.

[13] Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115-143.

[14] Blundell, R., Bond, S., & Windmeijer, F. (2000). Estimation in dynamic panel data models: Improving on the performance of the standard GMM estimator. IFS Working Papers W00/12, Institute for Fiscal Studies, London.

[15] Chenery, H. (1955). The role of industrialization in development programs. *The American Economic Review, 45*(1), 40-57.

[16] De Souza, E. S., Freire, F., & Pires, J. (2018). Determinants of CO_2 emissions in the MERCOSUR: The role of economic growth, and renewable and non-renewable energy. *Journal of Environmental Science and Pollution Research, 25*, 20769-20781.

[17] Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO_2 emissions. *Proceedings of the National Academy of Sciences, 94*(1), 175-179.

[18] Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science, 171*(3977), 1212-1217.

[19] Fischer, C. (2016). Environmental protection for sale: Strategic green industrial policy and climate finance. *Environmental and Resource Economics, 66*(3), 553-575.

[20] Friedl, B., & Getzner, M. (2003). Determinants of CO_2 emissions in a small open economy. *Ecological Economics, 45*(1), 133-148.

[21] Friedlingstein, P., Houghton, R., Marland, G., Hackler, J., Boden, T. A., Conway, T., Canadell, J., Raupach, M., Ciais, P., & Le Quere, C. (2010). Update on CO_2 emissions. *Nature Geoscience, 3*(12), 811-812.

[22] Fuchs, E., & Kirchain, R. (2010). Design for location? The impact of manufacturing off-shore on technology competitiveness in the optoelectronics industry. *Management Science, 56*(12), 2323-2349.

[23] Han, X., & Chatterjee, L. (1997). Impacts of growth and structural change on CO_2 emissions of developing countries. *World Development, 25*(3), 395-407.

[24] Haraguchi, N., Cheng, C. F. C., & Smeets, E. (2017). The importance of manufacturing in economic development: Has this changed?' *World Development, 93*, 293-315.

[25] Harrison, A., Martin, L., & Nataraj, S. (2017). Green industrial policy in emerging markets. *Annual Review of Resource Economics, 9*, 253-274.

[26] Hatzigeorgiou, E., Polatidis, H., & Haralambopoulos, D. (2011). CO_2 emissions, GDP and energy intensity: A multivariate cointegration and causality analysis for Greece, 1977-2007. *Applied Energy, 88*(4), 1377-1385.

[27] Hobday, M. (2013). Learning from Asia's success: Beyond simplistic 'lesson-making'. In A. Szirmai, W. Naudé, & L. Alcorta (Eds.), *Pathways to industrialization in the twenty-first century: New challenges and emerging paradigms* (pp. 133-153). Oxford: Oxford University Press.

[28] Kemp, R., & Never, B. (2017). Green transition, industrial policy, and economic development. *Oxford Review of Economic Policy, 33*(1), 66-84.

[29] Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control, 34*(7), 1187-1201.

[30] Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20*(1), 165-186.

[31] Lall, S. (1999). Introduction and setting. In S. Lall (Ed.), *The technological response to import liberalization in Sub Saharan Africa* (pp. 1-25). London: Palgrave Macmillan.

[32] Lall, S. (2000). The technological structure and performance of developing country manufactured exports, 1985-98. *Oxford Development Studies, 28*(3), 337-369.

[33] Li, K., & Lin, B. (2015). Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: Does the level of development matter? *Renewable and Sustainable Energy Reviews, 52*, 1107-1122.

[34] Lin, B., Omoju, O. E., & Okonkwo, J. U. (2015). Impact of industrialisation on CO_2 emissions in Nigeria. *Renewable and Sustainable Energy Reviews, 52*, 1228-1239.

[35] Liu, X., & Bae, J. (2018). Urbanization and industrialization impact of CO_2 emissions in China. *Journal of Cleaner Production, 172*, 178-186.

[36] Marsiglio, S., Ansuategi, A., & Gallastegui, M. C. (2016). The environmental Kuznets curve and the structural change hypothesis. *Environmental and Resource Economics, 63*(1), 265-288.

[37] Matsuo, T., & Schmidt, T. S. (2019). Managing tradeoffs in green industrial policies: The role of renewable energy policy design. *World Development, 122*, 11-26.

[38] Minx, J. C., Baiocchi, G., Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2011). A carbonizing dragon: China's fast growing CO_2 emissions revisited. *Environmental Science & Technology, 45*(21), 9144-9153.

[39] Montobbio, F., & Rampa, F. (2005). The impact of technology and structural change on export performance in nine developing countries. *World Development, 33*(4), 527-547.

[40] Nakicenovic, N., Kolp, P., Riahi, K., Kainuma, M., & Hanaoka, T. (2006). Assessment of emissions scenarios revisited. *Environmental Economics and Policy Studies, 7*, 137-173.

[41] Okereke, C., Coke, A., Geebreyesus, M., Ginbo, T., Wakeford, J. J., & Mulugetta, Y. (2019). Governing green industrialisation in Africa: Assessing key parameters for a sustainable socio-technical transition in the context of Ethiopia. *World Development, 115*, 279-290.

[42] Organisation for Economic Co-operation and Development (OECD). (2003). *OECD Science, Technology and Industry Scoreboard 2003.* Paris: OECD Publishing.

[43] Padilla, E. (2017). What can developing countries gain from a green transformation? In T. Altenburg & C. Assmann (Eds.), *Green industrial policy. Concept, policies, country experiences* (pp. 22-37). Geneva & Bonn: UN Environment; German Development Institute/Deutsches Institut für Entwicklungspolitik (DIE).

[44] Pasche, M. (2002). Technical progress, structural change, and the environmental Kuznets curve. *Ecological Economics, 42*(3), 381-389.

[45] Pavitt, K. (1984). Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy, 13*(6), 343-373.

[46] Pisano, G., & Shih, W. (2012). *Producing prosperity: Why America needs a manufacturing renaissance.* Boston, MA: Harvard Business Review Press.

[47] Pollin, R. (2020). An industrial policy framework to advance a global green new deal. In J.-J. Chang, C. Cramer, R. Kozul-Wright, & A. Oqubay (Eds.), *The Oxford handbook of industrial policy.* Oxford: Oxford University Press.

[48] Poumanyvong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. *Ecological Economics, 70*(1), 434-444.

[49] Raheem, I. D., & Ogebe, J. O. (2017). CO_2 emissions, urbanization and industrialization: Evidence from a direct and indirect heterogeneous panel analysis. *Management of Environmental Quality, 28*(6), 851-867.

[50] Rodrik, D. (2014). Green industrial policy. *Oxford Review of Economic Policy, 30*(3), 469-491.

[51] Seyoum, B. (2004). The role of factor conditions in high-technology exports: An empirical examination. *The Journal of High Technology Management Research, 15*(1), 145-162.

[52] Szirmai, A. (2012). Industrialisation as an engine of growth in developing countries, 1950-2005. *Structural Change and Economic Dynamics, 23*(4), 406-420.

[53] Szirmai, A., Naudé, W., & Alcorta, L. (2013). Introduction and overview: The past, present, and future of industrialization. In A. Szirmai, W. Naudé, & L. Alcorta (Eds.), *Pathways to industrialization in the twenty-first century: New challenges and emerging paradigms* (pp. 1-61). Oxford: Oxford University Press.

[54] Tang, C. F., & Tan, B. W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy, 79*, 447-454.

[55] Tassey, G. (2010). Rationales and mechanisms for revitalizing U.S. manufacturing R&D strategies. *The Journal of Technology Transfer, 35*(3), 283-333.

[56] Timmons Roberts, J., & Grimes, P. E. (1997). Carbon intensity and economic development 1962–1991: A brief exploration of the environmental Kuznets curve. *World Development, 25*(1), 191-198.

[57] Tregenna, F. (2009). Characterising deindustrialisation: An analysis of changes in manufacturing employment and output internationally. *Cambridge Journal of Economics, 33*(3), 433-466.

[58] Tregenna, F. (2015). Deindustrialisation, structural change and sustainable economic growth. MERIT Working Papers 032, Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT), United Nations University.

[59] Tregenna, F. (2016). Deindustrialisation and premature deindustrialization. In J. Ghosh, R. Kattel, & E. Reinert (Eds.), *Elgar handbook of alternative theories of economic development* (pp. 710-728).Cheltenham: Edward Elgar.

[60] Tregenna, F., & Andreoni, A. (2020). Deindustrialisation reconsidered: Structural shifts and sectoral heterogeneity. Working Paper Series (IIPP WP 2020-06), UCL Institute for Innovation and Public Purpose, University College London, London. Retrieved from https://www.ucl.ac.uk/bartlett/public-purpose/wp2020-06

[61] United Nations Industrial Development Organization (UNIDO). (2005). *Capability building for catching-up: Historical, empirical and policy dimensions*. Industrial Development Report, UNIDO, Vienna.

[62] United Nations Industrial Development Organization (UNIDO). (2016). *Industrialization in Africa and least developed countries. Boosting growth, creating jobs, promoting inclusiveness and sustainability*. A report to the G20 Development Working Group, Vienna.

[63] Upadhyaya, S. (2013). Country grouping in UNIDO statistics. Development Policy, Statistics and Research Branch Working Paper 1/2013, UNIDO, Vienna.

[64] Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics, 126*(1), 25-51.

[65] Xu, B., & Lin, B. (2015). How industrialization and urbanization process impacts on CO_2 emissions in China: Evidence from nonparametric additive regression models. *Energy Economics, 48*, 188-202.

[66] Xu, R., & Lin, B. (2017). Why are there large regional differences in CO2 emissions? Evidence from China's manufacturing industry. *Journal of Cleaner Production, 140*, 1330-1343.

[67] Yassin, J., & Aralas, S. (2019). Does the de-industrialization and tertiarization process decarbonize emissions in Asian countries? *International Journal of Accounting, 4*(17), 76-85.

[68] Zhang, L. Y. (2012). Does climate change make industrialization an obsolete development strategy for cities in the South? In D. Hoornweg, M. Frieire, J. M. Lee, P. Bpada-Tata, & B. Yueh (Eds.), *Cities and climate change: Responding to an urgent agenda* (pp. 564-581). Washington, DC: The World Bank.

[69] Zhang, Y. Z., Liu, Z., Zhang, H., & Tan, T. D. (2014). The impact of economic growth, industrial structure and urbanization on carbon emission intensity in China. *Natural Hazards, 73*(1), 579-595.

[70] Zhu, Z., Liu, Y., Tian, X., Wang, Y., & Zhang, Y. (2017). CO_2 emissions from the industrialization and urbanization processes in the manufacturing center Tianjin in China. *Journal of Cleaner Production, 168*, 867-875.

Table 1: Summary statistics (1991–2014)

Variable	Variable description	Mean	Std. dev.	Min.	Max.	Source
CO_2 emissions (kt)	CO_2 emissions (kilotons)	237 493.5	842 387.2	722.399	1.03e+0	WDI
CO_2 emissions (mt) per capita	CO_2 emissions (metric tons) per capita	2.899	3.358	.017	19.529	WDI
Manufacturing VA	Manufacturing value added (% of GDP)	15.294	5.875	1.234	37.508	WDI
Medium- and high-tech VA	Medium- and high-technology value added share in total manufacturing (%)	21.518	12.619	.248	57.188	UNIDO
Low-tech VA	Low-technology value added share in total manufacturing (%)	78.482	12.620	42.812	99.751	UNIDO
High-tech X	High-technology exports share in total manufactured exports (%)	8.865	12.895	.0002	74.994	WDI
Medium-tech X	Medium-technology exports share in total manufactured exports (%)	20.207	13.530	.014	81.525	WDI
Low-tech X	Low-technology exports share in total manufactured exports (%)	70.927	18.969	16.902	98.989	WDI
GDP per capita	GDP per capita	9 034.476	8 555.411	354.284	52 789.43	WDI
Services	Services value added (% of GDP)	49.790	10.978	5.592	93.723	WDI
Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	37.391	30.135	.006	98.343	WDI
Fossil fuel energy consumption	Fossil fuel energy consumption (% of total final energy consumption)	63.050	29.389	1.640	99.997	WDI
Trade	Trade (% of GDP)	72.273	46.691	13.753	442.62	WDI
Domestic credit	Domestic credit by financial sector (% of GDP)	50.559	40.944	-10.152	235.994	WDI
Urbanisation	Urbanisation (% of total population)	23.881	14.345	2.191	100	WDI

Source: Authors' calculations based on World Bank WDI and UNIDO CIP data.
Note: Both measures of CO_2 emissions, and GDP per capita and its square, enter the regressions in natural logs; values are shown here in unlogged form.

Table 2: Manufacturing value added and CO_2 emissions (1991–2014)

Two-step GMM estimation	(1)	(2)	(3)	(4)
	CO_2 emissions (kt) (ln)		CO_2 emissions (mt) per capita (ln)	
	Linear	**Quadratic**	**Linear**	**Quadratic**
L. CO_2 emissions (kt) (ln)	0.315***	0.228***		
	(-0.033)	(-0.059)		
L. CO_2 emissions (mt) per capita (ln)			0.235***	0.200***
			(-0.037)	(-0.046)
Manufacturing VA	0.007**	0.029***	0.01	0.017
	(-0.001)	(-0.004)	(-0.002)	(-0.003)
Manufacturing VA square		-0.026***		0.002
		(-8E-05)		(-1E-04)
GDP per capita (ln)	0.000	1.863***	0.227**	1.239***
	(-0.064)	(-1.083)	(-0.152)	(-0.367)
GDP per capita (ln) square		-1.767***		-0.851***
		(-0.060)		(-0.019)
Services	-0.011***	-0.009**	-0.019***	-0.018***
	(-0.001)	(-0.001)	(-0.001)	(-0.001)
Renewable energy consumption	-0.057*	-0.018	-0.084	-0.056
	(-0.002)	(-0.002)	(-0.003)	(-0.004)
Fossil fuel energy consumption	0.259***	0.289***	0.363***	0.317***
	(-0.002)	(-0.002)	(-0.003)	(-0.004)
Trade	-0.01	-0.002	0.004	0.007
	(0.000)	(0.000)	(0.000)	(0.000)
Domestic credit	-0.029***	-0.023**	-0.011	-0.009
	(0.000)	(0.000)	(-0.001)	(-0.001)
Urbanisation	-0.006	0.04	0.168	0.236
	(-0.004)	(-0.005)	(-0.012)	(-0.016)
Wald Chi squared	17657.31	30741.91	7314.15	8007.46
(p value)	(0.000)	(0.000)	(0.000)	(0.000)
AR (1)	-3.441	-3.364	-2.631	-2.137
(p value)	(0.000)	(0.000)	(0.008)	(0.032)
AR (2)	-.930	-.772	-.537	-.1058
(p value)	(0.353)	(0.440)	(0.591)	(0.916)
No. of countries	56	56	56	56
Observations	1 152	1 152	1 152	1 152

Standardised beta coefficients; Windmeijer bias-corrected robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Manufacturing value added and CO_2 emissions, by technology intensity (1991–2014)

Two-step GMM estimation	**(1)**	**(2)**	**(3)**	**(4)**
	CO_2 emissions (kt) (ln)	**CO_2 emissions (mt) per capita (ln)**	**CO_2 emissions (kt) (ln)**	**CO_2 emissions (mt) per capita (ln)**
L. CO_2 emissions (kt) (ln)	0.478^{***}		0.396^{***}	
	(0.009)		(0.0212)	
L. CO_2 emissions (mt) per capita (ln)		0.190^{***}		0.302^{***}
		(0.041)		(0.0219)
Medium- and high-tech VA	-0.059^{***}	-0.062^{**}		
	(0.002)	(0.003)		
Medium- and high-tech VA square	0.034^{***}	0.039^{*}		
	(0.000)	(0.000)		
Low-tech VA			0.268^{***}	0.148^{***}
			(7.02e-15)	(6.61e-15)
Low-tech VA square			-0.187^{**}	-0.248^{**}
			(1.26e-28)	(1.21e-28)
GDP per capita (ln)	0.586^{***}	0.984^{***}	1.290^{***}	1.093^{***}
	(0.382)	(0.362)	(0.299)	(0.205)
GDP per capita (ln) square	-0.445^{**}	-0.665^{***}	-1.135^{***}	-0.900^{***}
	(0.021)	(0.021)	(0.0167)	(0.0115)
Services	-0.016^{***}	-0.022^{***}	-0.011^{**}	-0.028^{***}
	(0.000)	(0.001)	(0.000847)	(0.000811)
Renewable energy consumption	-0.122^{***}	-0.046	-0.073^{**}	-0.119^{***}
	(0.001)	(0.003)	(0.00190)	(0.00182)
Fossil fuel energy consumption	0.145^{***}	0.363^{***}	0.179^{***}	0.234^{***}
	(0.001)	(0.004)	(0.00187)	(0.00178)
Trade	0.025^{***}	0.012	0.033^{***}	0.008
	(0.000)	(0.003)	(0.000260)	(0.000258)
Domestic credit	-0.014^{***}	-0.006	-0.012^{*}	-0.025^{***}
	(0.000)	(0.000)	(0.000286)	(0.000266)
Urbanisation	0.229^{***}	0.314^{**}	0.181^{***}	0.097^{**}
	(0.004)	(0.014)	(0.00422)	(0.00380)
Wald Chi squared	109 490.44	15 207.70	2 542.98	1 664.62
(p-value)	0.000	0.000	0.000	0.000
AR (1)	-3.982	-1.280	-3.825	-3.618
(p-value)	0.000	0.000	0.000	0.000
AR (2)	-.7566	.530	-.741	-1.096
(p-value)	0.449	0.595	0.458	0.273
No. of countries	56	56	56	56
Observations	1152	1152	1152	1152

Standardised beta coefficients; Windmeijer bias-corrected robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: In columns 1 and 2, the explanatory variables of interest are the linear and quadratic terms of 'Medium- and high-tech VA' (Medium- and high-technology value added share in total manufacturing (%)). In columns 3 and 4, the explanatory variables of interest are the equivalent terms for 'Low-tech VA'. In each case, results are shown for the two alternative dependent variables: CO_2 emissions (kilotons) (columns 1 and 3) and CO_2 emissions (metric tons) per capita (columns 2 and 4), both in natural logs.

Table 4: Manufacturing exports and CO_2 emissions, by technology intensity (1991–2014)

Two-step GMM estimation	(1)	(2)	(3)	(4)	(5)	(6)
	CO_2 emissions (kt) (ln)	CO_2 emissions (mt) per capita (ln)	CO_2 emissions (kt) (ln)	CO_2 emissions (mt) per capita	CO_2 emissions (kt) (ln)	CO_2 emissions (mt) per capita (ln)
L. CO_2 emissions (kt) (ln)	0.280***		0.269***		0.286***	
	(0.0232)		(0.0234)		(0.0236)	
L. CO_2 emissions (mt) per capita (ln)		0.241***		0.227***		0.247***
		(0.0233)		(0.0235)		(0.0237)
High-tech X	-0.023**	-0.030**				
	(0.00135)	(0.00131)				
High-tech X square	0.024***	0.028**				
	(0.0000227)	(0.0000220)				
Medium-tech X			-0.009*	-0.017**		
			(0.000608)	(0.000591)		
Medium-tech X square			0.016***	0.025***		
			(0.0000105)	(0.0000101)		
Low-tech X					0.030***	0.037***
					(0.00135)	(0.00130)
Low-tech X square					0.031***	0.034***
					(0.0000229)	(0.0000221)
GDP per capita (ln)	0.834***	0.990***	0.846***	0.986***	0.850***	1.008***
	(0.260)	(0.210)	(0.259)	(0.208)	(0.265)	(0.213)
GDP per capita (ln) square	-0.833***	-0.852***	-0.841***	-0.844***	-0.846***	-0.864***
	(0.0142)	(0.0115)	(0.0142)	(0.0114)	(0.0145)	(0.0117)
Services	-0.011**	-0.012*	-0.014***	-0.015**	-0.014***	-0.014**
	(0.000844)	(0.000819)	(0.000855)	(0.000829)	(0.000885)	(0.000853)
Renewable energy consumption	0.025	0.023	0.024	0.016	0.038	0.025
	(0.00189)	(0.00176)	(0.00187)	(0.00175)	(0.00184)	(0.00173)
Fossil fuel energy consumption	0.297***	0.437***	0.294***	0.430***	0.309***	0.434***
	(0.00195)	(0.00187)	(0.00194)	(0.00186)	(0.00198)	(0.00190)
Trade	-0.005	-0.001	-0.006	-0.005	-0.005	-0.000
	(0.000280)	(0.000267)	(0.000276)	(0.000263)	(0.000285)	(0.000271)
Domestic credit	-0.041***	-0.051***	-0.038***	-0.047***	-0.054***	-0.063***
	(0.000262)	(0.000254)	(0.000261)	(0.000254)	(0.000279)	(0.000267)
Urbanisation	-0.046	-0.038	-0.049	-0.039	-0.054	-0.044
	(0.00409)	(0.00393)	(0.00409)	(0.00392)	(0.00414)	(0.00397)

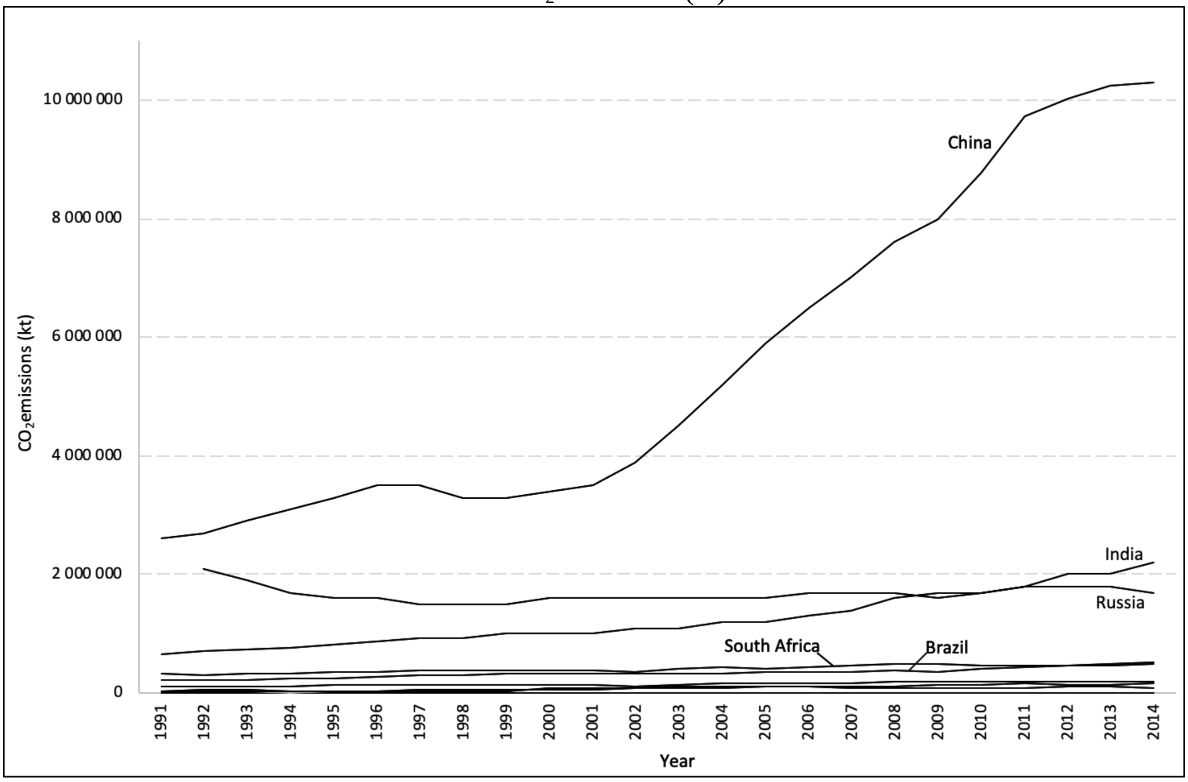
Wald Chi squared	7 467.90	3 225.23	7 503.46	3 250.64	7 512.10	3 245.72
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
AR (1)	-2.586	-.225	-2.630	-1.349	-2.194	-.807
(p-value)	(0.009)	(0.001)	(0.008)	(0.007)	(0.028)	(0.019)
AR (2)	-1.542	-.164	-1.600	-1.073	-1.393	-1.136
(p-value)	(0.123)	(0.869)	(0.109)	(0.283)	(0.163)	(0.255)
No. of countries	56	56	56	56	56	56

Standardised beta coefficients; Windmeijer bias-corrected robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: In columns 1 and 2, the explanatory variables of interest are the linear and quadratic terms of 'High-tech X' (High-technology exports' share in total manufactured exports (%)). In columns 3 and 4, the explanatory variables of interest are the equivalent terms for 'Medium-tech X' and in columns 5 and 6 the equivalent terms for 'Low-tech X'. For each, the results are shown for the two alternative dependent variables: CO_2 emissions (kilotons) (columns 1, 3, and 5) and CO_2 emissions (metric tons) per capita (columns 2, 4, and 6), both in natural logs.

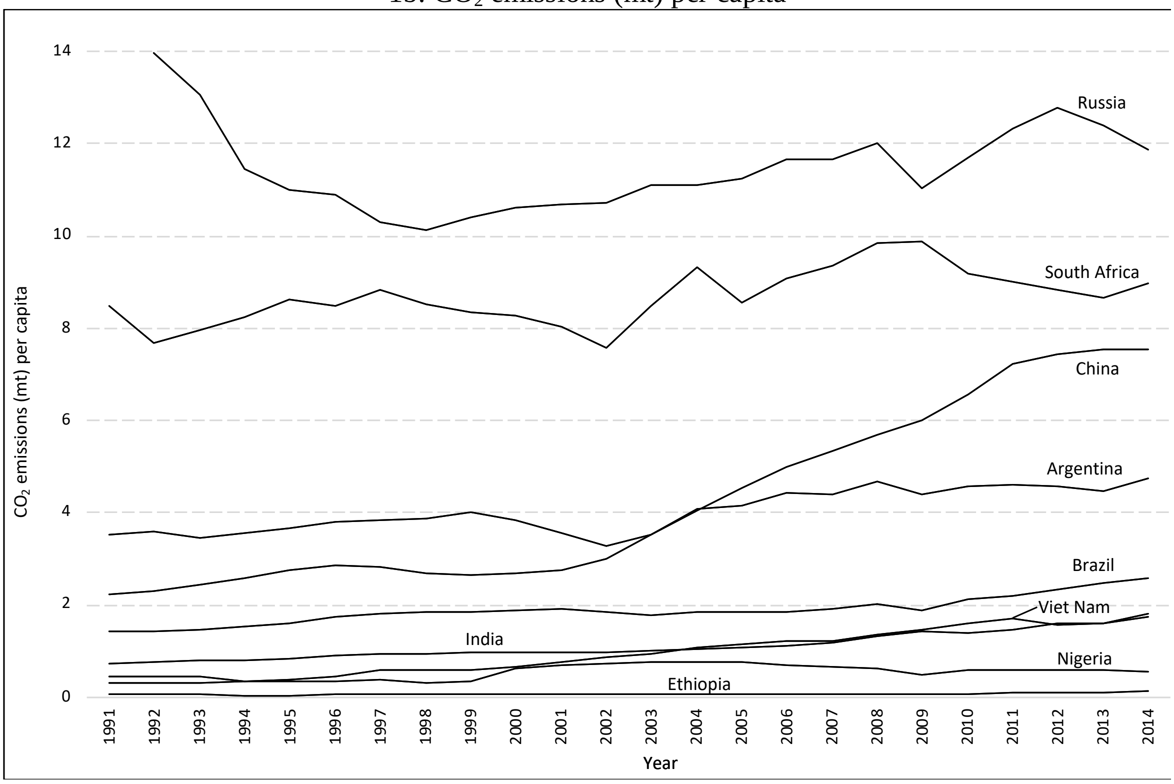
Figure 1: CO_2 emissions in selected developing countries (1991 to 2014)

1a: CO_2 emissions (kt)



Note: The lower series are for Argentina, Vietnam, Nigeria and Ethiopia; labels not shown due to space.

1b: CO_2 emissions (mt) per capita



Source: Authors' calculations from WDI.

Appendix

Table A.1: Classification of manufacturing industries according to their technology intensity

Category of technology intensity	**Industries**
High-technology industries	Aircraft and spacecraft; pharmaceuticals; electronics components; office, accounting, and computing machinery; radio, TV, and communications equipment; medical, precision and optical instruments.
Medium-technology industries	Electrical machinery and apparatus; motor vehicles; trailers and semi-trailers; chemicals excluding pharmaceuticals; railroad equipment and transport equipment; machinery equipment; building and repairing of ships and boats; rubber and plastics products; coke, refined petroleum products, and nuclear fuel; other non-metallic mineral products; basic metals and fabricated metal products.
Low-technology industries	Manufacturing, n.e.c.; recycling wood, pulp, paper, paper products, printing, and publishing; food products, beverages, and tobacco; textiles, textile products, leather, and footwear.

Source: OECD (2003)

Table A.2: List of countries

1. Argentina	29. Malaysia
2. Armenia	30. Mexico
3. Azerbaijan	31. Morocco
4. Bangladesh	32. Mozambique
5. Belarus	33. Nepal
6. Bolivia (Plurinational State of)	34. Niger
7. Brazil	35. Nigeria
8. Bulgaria	36. Pakistan
9. Cambodia	37. Panama
10. Cameroon	38. Paraguay
11. Chile	39. Peru
12. China	40. Philippines
13. China, Hong Kong SAR	41. Russian Federation
14. Colombia	42. Saint Lucia
15. Congo	43. Saudi Arabia
16. Costa Rica	44. Senegal
17. Ecuador	45. Serbia
18. El Salvador	46. South Africa
19. Ghana	47. Thailand
20. Guatemala	48. Turkey
21. Haiti	49. Ukraine
22. India	50. United Republic of Tanzania
23. Indonesia	51. Uruguay
24. Iran (Islamic Republic of)	52. Venezuela (Bolivarian Republic of)
25. Jordan	53. Viet Nam
26. Kazakhstan	54. Yemen
27. Kenya	55. Zambia
28. Lebanon	56. Zimbabwe