The relationship between industrial structure and carbon intensity at different stages of economic development: an analysis based on a dynamic threshold panel model

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Abstract

Achieving the win-win goal of economic development and carbon intensity reduction, especially through industrial restructuring, is a challenge involving uncertainty and complexity. Determining which industry is green and whether it should be encouraged or limited at different stages of economic development are key issues that should initially be addressed. The relationship between industrial structure and carbon intensity was systematically analyzed in 21 industrial sectors for the period of 1971–2014 in eight developed countries, with different levels of economic development, using an extended dynamic threshold model. The results indicated that there is a relationship between industrial composition and carbon intensity, and that the impact of industrial structure on carbon intensity can be classified into four categories: contaminated, pollution-clean, cleaning hysteresis, and enhanced cleaning. The proportion of sectors with a certain relationship between GDP and carbon intensity will change at a certain important income level. The change points for most sectors were US$ 525 and US$ 3,904 GDP per capita, which represent the points at which a country enters the mid-industrialization and high-tech industrialization stages, respectively. Therefore, the government and enterprises must upgrade their industrial structure as the national GDP increases, adjust the proportion of sectors operating according to the industrial characteristics, and improve production technology through environmental regulations..

Introduction

Rapid economic development has led to enormous energy consumption and an unprecedented rise in greenhouse gas (GHG) emissions, which is the main driving force of global climate change. Given that CO_2 emissions accounts for the majority of anthropogenic GHG emissions [1] and CO_2 emissions are expected to increase by 30% above the 2010 level by 2030 [2], many researchers and politicians have given increasing attention to the driving forces behind CO_2 emissions and the measures required to reduce them.

There is a also conflict regarding the allocation of mitigation measures between developed and developing countries.

Research Gap

With regard to the impact of structural changes on carbon intensity, a large number of studies have explored the effects of structural factors on CO_2 emissions, or carbon intensity, under the EKC framework from qualitative and quantitative perspectives. Some studies have used decomposition methods, econometric models, or input–output models to quantitatively measure the contribution of industrial restructuring to changes in CO_2 emissions.

In summary, there have been many empirical studies of the relationship between structural changes in industry and carbon intensity under the EKC framework, and theoretical analyses have also considered the separate interpretation of structural factors, although such studies are rare. This has proven that there is an interaction between structural changes, economic development, and CO_2 emissions. Other quantitative analyses have also provided evidence and reference materials for the analysis of structural factors. However, there are still some gaps that need to be filled. First, few studies have independently analyzed the relationship between industrial structure and carbon intensity. Second, although some studies have noted the issue of "national heterogeneity," changes in the relationship between carbon intensity and industrial structure for specific country groups with different levels of economic development have rarely been considered. Third, existing studies have considered only a few economic sectors over a narrow time range, which cannot provide a full understanding of the carbon intensity throughout different sectors.

Objectives

In this study, we explore the relationship between structural changes and carbon intensity in 21 industrial sectors of eight developed nations for the period from 1971 to 2014. To determine which sectors will drive the increase in carbon intensity following a growth in output, the dynamic threshold panel model was used to study the law of industrial structure and carbon intensity under different economic development levels.

Methodology

We first estimated the threshold value of the change between industrial structure and carbon intensity using the Hansen(1999) method and further used the "first-order difference GMM" (1991) to estimate the parameters between different threshold regimes. In this manner, we could control the lag effect, and endogenous and dynamic factors based on the dynamic panel estimation method. We found that the dependent variable of the two-order lags was significant and had the best fitting degree. Therefore, we chose the first-order and two-order lags to control for the continuity and inertia of the process of reducing carbon intensity. The single-threshold and double-threshold models are shown as examples in Eqs. below:

$$CI = \alpha_1 CI_{t-1} + \alpha_2 CI_{t-2} + \beta_1 IS_{it} I(CGDP_{it} \le \gamma) + \beta_2 IS_{it} I(CGDP_{it} > \gamma) + u_i + v_t + \varepsilon_{it}$$

$$CI = \alpha_1 CI_{t-1} + \alpha_2 CI_{t-2} + \beta_1 IS_{it} I(CGDP_{it} \le \gamma_1) + \beta_2 IS_{it} I(\gamma_1 < CGDP_{it} \le \gamma_2) + \beta_3 IS_{it} I(CGDP > \gamma_2) + u_i + v_t + \varepsilon_{it}$$

where *i* and *t* denote country and year, respectively. CGDP is gross domestic production per capita; I (·) represents the indicator function, and r is the threshold value. The observations were divided into two regimes depending on whether the threshold variable CGDP was less than or greater than the threshold value r. The regimes were distinguished by different regression slopes, B_1,B_2,B_3,U_i . V_t is the specific effect of the individual, ε_{it} is the specific effect of time, and it is a random disturbance.

Evolution of industrial structure and carbon intensity

Using the value added data for the 21 sectors of 8 countries from 1971 to 2014, we found significant changes in industrial structure and carbon intensity. First, with an increase in GDP, nearly all of the countries investigated showed a decreasing trend in secondary industry and an increasing trend in tertiary industry during these periods.

Second, the structure of manufacturing also changed. We divided the 16 sectors of manufacturing into two types according to the changes in the proportion of GDP they produce. One type was sectors where there was a general decline, including textiles etc. The main products produced by these sectors can easily be obtained by importing substitutes and their operations have been gradually transferred to newly industrialized countries or developing countries since the 1970s. This has led to a decline in the proportion of GDP produced by these sectors in their home country. The other type was sectors with a slight growth in the proportion of GDP produced, such as food and beverages; coke, refined petroleum products, nuclear fuel etc. Most of these sectors are capital-intensive industries or are closely related to the livelihood of individuals and therefore tend to stay in their home country.

Third, the trajectory of total carbon intensity showed a declining trend, with a different shape over time as the industrial structure changed. By the end of 2014, the carbon intensity of all eight developed countries was less than 0.50 kg/$, with the highest value of 0.46 kg/$ for South Korea and the lowest value of 0.10 kg/$ for France

The carbon intensity of the remaining countries monotonously declined since 1971.

The carbon intensity in Australia, Japan, and Korea had a gentle inverted U-shaped trend.

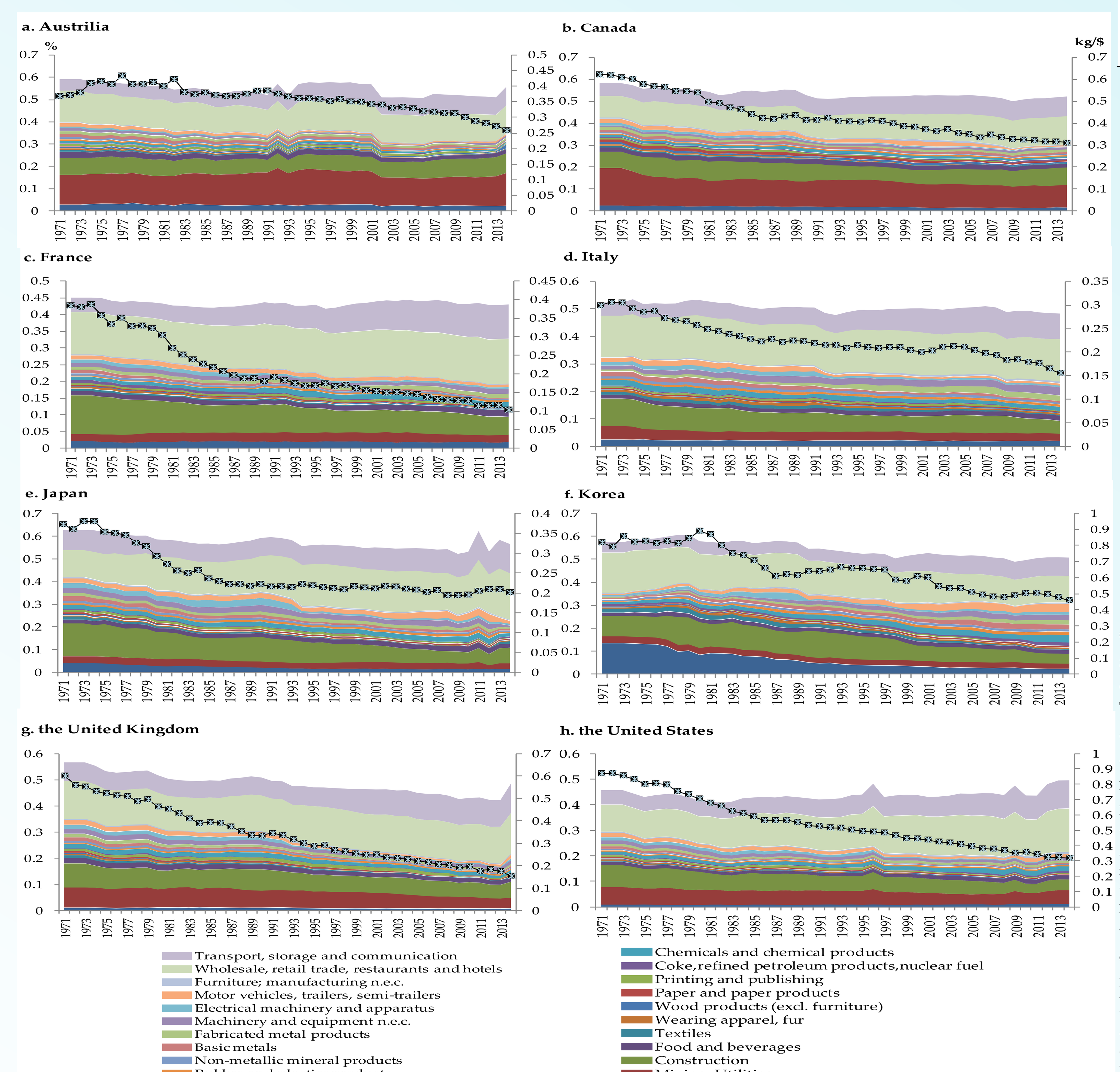


Figure 1. Changes in industrial value added for 21 sectors and carbon intensity in eight developed countries from 1971 to 2014

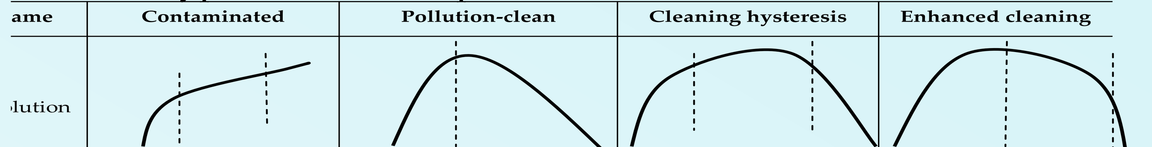
Results

Table 1. Regression results for the dynamic panel threshold model

Coefficients / Industrial sectors	Threshold Model	Threshold Value(CGDP)	IS	CIt-1	CIt-2	Constant
Agriculture	single	3.9040	0.1212 -0.3443	0.8928	0.0744	0.0114
Wearing apparel,fur	single	1.0930	17.6895 0.2791	0.8102	0.1508	0.0081
Chemicals and chemical products	single	0.5250	1.3122 -0.1573	0.8023	0.1640	0.0093
Electrical machinery and apparatus	single	3.9040	3.9146 0.0310	0.7305	0.2092	0.0147
Mining	single	0.5250	0.7991 0.2354	0.7907	0.1633	-0.0022
	double	0.5250 3.9040	2.0726 1.3994 0.2486	0.7324	0.1958	-0.0007
Food and beverages	single	0.5250	2.6868 0.3129	0.8061	0.1602	0.0014
	double	0.5250 3.9040	4.6989 2.0933 0.1224	0.7626	0.1865	0.0083
Paper and paper products	single	1.1030	13.5565 0.8924	0.7918	0.1521	0.0096
	double	3.9040 0.5250	21.2380 11.5593 0.5538	0.7721	0.1792	0.0070
Non-metallic mineral products	single	0.5250	7.0542 1.1897	0.7912	0.1713	0.0002
	double	0.5250 3.9040	14.1573 6.4491 1.2795	0.7021	0.2386	0.0030
Machinery and equipment	single	1.0710	8.0889 0.2928	0.7743	0.1737	0.0021
	double	0.5250 3.9040	10.5488 7.7271 0.2570	0.7338	0.2170	0.0003
Wholesale,retail trade,restaurants and hotels	single	1.1030	0.6553 0.1530	0.7985	0.1763	-0.0174
	double	0.5250 3.9040	0.6856 0.1780 -0.0410	0.7507	0.2004	0.0156
Basic metals	single	0.5250	1.0330 -0.4873	0.7966	0.1738	0.0104
	double	0.5250 3.9040	-1.2238 -3.5989 -0.9719	0.7680	0.2090	0.0148
	triple	0.5250 3.9040 7.7850	1.6666 -0.0827 -3.1659 -0.7097	0.7417	0.2329	0.0096

Coefficients / Industrial sectors	Threshold Model	Threshold Value(CGDP)	IS	CIt-1	CIt-2	Constant
Texitiles	single	3.9040	1.8358 0.0281	0.7693	0.1804	0.0112
Coke,refined petrroleum products,nuclear fuel	single	0.5250	3.8560 -0.6926	0.7935	0.1701	0.0115
Rubber and plastics products	single	0.5250	7.3756 -0.5781	0.7917	0.1700	0.0125
Funiture	single	0.5250	37.3630 -0.2241	0.7925	0.1743	0.0074
Construction	single	0.5250	0.3790 0.0088	0.7999	0.1678	0.0055
	double	0.5250 0.5880	0.7714 0.3526 0.0011	0.7185	0.2317	0.0091
Wood products	single	1.1150	12.7422 0.5275	0.7891	0.1590	0.0133
	double	3.9040 0.5880	49.4148 11.6754 0.3890	0.7448	0.2063	0.0108
Printing and publishing	single	1.1030	15.2494 0.5307	0.7655	0.1756	0.0114
	double	3.9040 0.5250	23.9480 13.1012 0.3273	0.7336	0.2143	0.0087
Fabricated metal products	single	0.5250	7.6639 -0.1651	0.7998	0.1671	0.0081
	double	0.5250 3.9040	17.8137 7.0554 0.1628	0.7233	0.2331	0.0042
Motor vehicles,trailers,semi-trailers	single	0.5250	3.0454 -0.0758	0.7979	0.1697	0.0070
	double	0.5250 3.9040	6.9519 3.7243 0.1445	0.7531	0.1974	0.0064
Transport,storage and communication	single	0.5250	1.1597 -0.0361	0.7947	0.1689	0.0105
	double	0.5250 3.9040	2.2547 0.5540 -0.1578	0.7065	0.2267	0.0276
Total manufacturing	single	0.5250	0.2263 -0.0069	0.8015	0.1661	0.0072
	double	0.5250 3.9040	0.7727 0.4343 0.1032	0.7484	0.2017	-0.0090

Table 2. The type of relationship between industrial structure and carbon intensity

ame	Contaminated	Pollution-clean	Cleaning hysteresis	Enhanced cleaning
lution				
ustrial ctors	Wearing apparel and fur; Electrical machinery and apparatus; Mining; Food and beverages; Textiles; Construction; Wood products; Paper and paper products; Non-metallic mineral products; Machinery and equipment; Printing and publishing;	Agriculture; Chemicals and chemical products; Coke, refined petroleum products, nuclear fuel; Furniture; Fabricated metal products; Motor vehicles, trailers, semi-trailers; Total manufacturing	Wholesale, retail trade, restaurants and hotels; Transport, storage and communication	Basic metals

Conclusion

Generally, economic development contributes to a decrease in industrial carbon intensity. The shape and inflection point of the curves describing the relationship between structural changes and carbon intensity were found to be significantly different among the industrial sectors investigated. This difference was mainly attributed to the internal characteristics regarding their energy demands and spatial transfer. For each sector, there were several procedures that consumed different amounts of energy and emitted CO_2 at various levels. These procedures could be located in different countries. With increasing labor and land costs, and levels of environmental regulation in developed countries, some standard procedures and raw material processing will be transferred to newly industrialized countries, such as the Asian tigers and China, which will lead to a proportional decrease in the GDP contribution of some sectors.

In addition, national environmental protection policies and regulations could have a profound impact on a sector's output and the upgrading of their production processes. Since the oil crisis of the 1970s, the automotive sector has taken many measures to reduce fuel consumption. For example, making more efficient engines, reducing the weight of raw materials used (such as replacing steel with plastics and non-ferrous metals), reducing the size of vehicles (especially in North America), and increasing the use of electronic equipment to control the engine. Safety and anti-pollution control measures imposed by governments in developed countries have also put pressure on changes in automobile design. All these measures have promoted the decline of carbon intensity at the same time that GDP is increasing.

The regression results of the model also showed that structural change points for most sectors existed at US$ 525 and US$ 3,904 GDP per capita. The effects of structural changes on both sides of these two turning points had significant impacts on carbon intensity.

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