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Decomposition analysis of the pollution intensities in the case of the United Kingdom

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Abstract: This paper examines the changes to pollution intensities (SO_2, NO_x, CO and CO_2) of the United Kingdom, by using the Divisia index decomposition technique. The paper decomposes the drivers of the changes in pollution intensities into not only technology contribution and composition contribution but also into physical capital intensity contribution. This is because an increase in physical capital will lead to further use of energy and resources, which will further impact the environment. Compared to past studies, this paper extends the analysis to each industrial sector and includes more focused policy implications. The results find that the aggregate pollution intensity has declined during the period examined. As for SO_2 and NO_x, the technology effect was the largest contributor for the decline in aggregate pollution intensity, during a period where economic instruments such as pollution taxes were not yet effectively applied to combat environmental issues, but major environmental statutory frameworks to regulate air pollution were developed along with voluntary measures such as environment management systems. On the other hand, concerning CO and CO_2 over the same time period observed, the contribution of technology effect for the aggregate intensity was small, compared with SO_2, and NO_x, which implies that economic instruments such as emission trading may be necessary for these pollutant.

Subjects: Development Studies, Environment, Social Work, Urban Studies; Economics, Finance, Business & Industry; Geography

Keywords: decomposition analysis; pollution intensities; physical capital; United Kingdom

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PUBLIC INTEREST STATEMENT

Since the Earth Summit was held in Rio de Janeiro in 1992, social awareness of the environment has grown globally and a number of measures have been taken to address pollution and improve the environment. As a result, some developed countries such as the United Kingdom (UK) have been able to significantly reduce pollution. This paper attempts to analyse the impact on air pollution in the UK by applying a decomposition analysis to observe whether technology, shifts in industrial compositions and physical capital intensity have contributed towards the reduction in air pollution.

1. Introduction

Since the Earth Summit was held in Rio de Janeiro in 1992, social awareness of the environment has grown globally. Under such influence, a vast amount of research has been conducted across many disciplines applying various methods to understand what factors had been effective towards improving the environment. For instance, research on the Environmental Kutznets Curve has studied how economic indicators such as income and trade influence the impact on the environment (Antweiler, Copeland, & Taylor, 2001a, 2001b; Cole, Rayner, & Bates, 1997; Grossman & Krueger, 1995). At an early stage, the studies applying a decomposition analysis have observed whether technology, regulations or shifts in industrial compositions have had an impact on energy intensity which is closely linked with environmental impacts (e.g. Boyd, Hanson, & Sterner, 1988; Choi & Ang, 2003; Huang, 1992). Similar studies continue to be conducted across numerous countries (Choi & Oh, 2014; Ma & Stern, 2008; Shahiduzzaman, Layton, & Alam, 2015; Zhang, Li, Zhou, Zhang, & Gao, 2016). As further concerns grow over environmental issues, the decomposition analysis has been applied to pollution intensity. For example, Shyamal and Bhattacharya (2004) have examined the intensity of carbon dioxide (CO_2) emission for India and there are extensive studies on CO_2 emission for China (Ang & Xu, 2013; Shao et al., 2014; Su & Ang, 2012; Zhao et al., 2010). These studies are focused on CO_2 intensity, but Lin and Chang (1996) have analysed three pollutants applying the decomposition analysis for the region of Taiwan. This paper tries to further build on these studies by examining four pollutants for the United Kingdom (UK) over the period from 1990 to 1997. The reason this period in the UK was chosen, is because the adoption of appropriate economic instruments such as environmental taxes and emission trading schemes was still limited during this time and so it will be possible to observe how other environmental measures including voluntary actions such as the environmental management system (EMS) have had an impact on pollution emission. Moreover, major environmental statutory frameworks that provided the foundation in air quality regulations were introduced during this period. The 1990 Environmental Protection Act that makes provision for the improved control of pollution arising from certain industrial and other processes was introduced. The Clean Air Act in 1993 introduced Smoke Control Areas to improve air quality by the burning of cleaner fuels in these areas by controlling domestic and industrial smoke with the intention of helping the UK meet air quality standards set by European law. The Environment Act of 1995 provided a new statutory framework for local air quality management. Understanding how regulations and voluntary measures may be effective or limited in controlling pollutants compared to economic instruments will provide insight into future environmental policy development. This study applies the decomposition analysis on pollution intensity, the effects of technology and regulations, and the effects of industrial composition in order to examine how each effect has impacted pollution intensity. There are similar studies in the past by Cole, Elliott, and Shimamoto (2005a) and Bruneau and Renzetti (2009). However, this paper adds to these studies by including the following analyses. First difference is it has added physical capital intensity as another effect contributing to changes in pollution intensity. This is because an increase in physical capital will lead to further use of energy and resources, which means that the higher physical capital intensity will cause a larger amount of pollution (Cole, Elliott, & Shimamoto, 2005b). The second contribution of this paper is that it has included another pollutant, carbon monoxide (CO) emission. The third is that the study extends to analyse each industrial sector and includes more focused policy implications. The method used builds upon the method applied in Choi and Ang (2003)'s analysis by including physical capital intensity.

This study is organised into four sections. The Section 2 explains the methodology of the decomposition analysis applied to the aggregated pollution intensity. In Section 3, the empirical analysis of each pollution intensity (sulphur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide) for the UK during the 1990s is performed. The Section 4 will provide the conclusion and an explanation on policy implications.

2. Methodology

The methodology applied here uses the decomposition analysis to examine energy intensity and applies it to pollution intensity. During the process, it includes the physical capital intensity effect to form the model.

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E denotes the total pollution emission of the industry and Y denotes the total industrial production in a country. Based on the assumption that there are n industrial sectors, and E_k and Y_k are, respectively, the pollution emission and production level in the k sector. As for sector k, the sectoral pollution intensity per capita for sector k, is determined by $EP_k = E_k/P_k$, and the sectoral capital intensity is $PI_k = P_k/Y_k$ and the industrial production share is $S_k = Y_k/Y$. The aggregate pollution intensity $EI = E/Y$ can then be described as

$$EI = \sum_{k=1}^{n} \frac{E_k}{P_k}\frac{P_k}{Y_k}\frac{Y_k}{Y} = \sum_{k=1}^{n} EP_k PI_k S_k \tag{1}$$

That is why the aggregate pollution intensity, EI, can be influenced by changes to the pollutants–physical capital ratio EP_k, changes to the physical capital intensity PI_k and/or changes to the industry composition S_k. From applying the study by Choi and Ang (2003) analysis, these three effects are separated by using Equation (2).

$$\begin{aligned}\frac{EI_t}{EI_0} = \exp&\left\{\sum_{k=1}^{n}\frac{L(EP_{k,t}PI_{k,t}S_{k,t},\, EP_{k,0}PI_{k,0}S_{k,0})}{L(EI_t,\, EI_0)}\ln\frac{EP_{k,t}}{EP_{k,0}}\right\}\\ \exp&\left\{\sum_{k=1}^{n}\frac{L(EP_{k,t}PI_{k,t}S_{k,t},\, EP_{k,0}PI_{k,t}S_{k,0})}{L(EI_t,\, EI_0)}\ln\frac{PI_{k,t}}{PI_{k,0}}\right\}\\ \exp&\left\{\sum_{k=1}^{n}\frac{L(EP_{k,t}PI_{k,t}S_{k,t},\, EP_{k,0}PI_{k,0}S_{k,0})}{L(EI_t,\, EI_0)}\ln\frac{S_{k,t}}{S_{k,0}}\right\}\end{aligned} \tag{2}$$

where L means a log-mean function and EI_t means the aggregate emissions intensity in time period t and EI_0 means the same intensity in time period 0. The three additional terms on the right-hand side represent the pollutants–physical capital effect (technology effect), physical capital intensity and the composition effect, respectively. Note that $\frac{L(EP_{k,t}PI_{k,t}S_{k,t},EP_{k0}PI_{k,0}S_{k,0})}{L(EI_t,EI_0)}$ is $\frac{(EI_{k,t}-EI_{k,0})/(\ln EI_{k,t}-\ln EI_{k,0})}{(EI_t-EI_0)/(\ln EI_t-\ln EI_0)}$.

Industry level pollution emissions data are provided by Eurostat as part of the National Accounting Matrix including Environmental Accounts (NAMEA). In NAMEA, emissions data are compiled in a manner that is consistent with the way economic activities are quantified in national accounts. This paper utilises NAMEA emissions data for sulphur dioxide (SO_2), nitrogen oxides (NO_x), CO and carbon dioxide (CO_2), for the 22 NACE classified manufacturing sectors for the UK for the period 1990–1997. The value added data is derived from the OECD STAN database. Physical capital data also stem from the OECD STAN data-set.

3. Empirical analysis

As indicated in Figure 1, the aggregate intensity of CO was maintained until 1993 and then shows a declining trend. Until 1993, the drive for the composition effect and physical capital intensity effect to decrease the aggregate CO intensity was countered by the negative impact from the technology effect. This means that until 1993, the slight shift towards cleaner industries and the less reliance on physical capital had negated the influence from the inefficient technology used in production to increase CO intensity. On the other hand, from 1993, the main driver behind the decrease in the aggregate CO intensity was the technology effect. This suggests that the improvement in technology which is examined by the reduction in the CO emission per physical capital was effective. Overall, the physical capital intensity effect and composition effect were the largest contributors towards the decline in aggregate CO intensity. It was also observed that for aggregate CO intensity and all three of the effects had improved compared to 1990, the beginning of the observation. This suggests that a shift towards cleaner industries, less reliance on physical capital and the reduction in pollutant–physical capital ratio has all contributed towards the decline in aggregate CO intensity.

Figure 1. Decomposition of aggregate CO intensity.

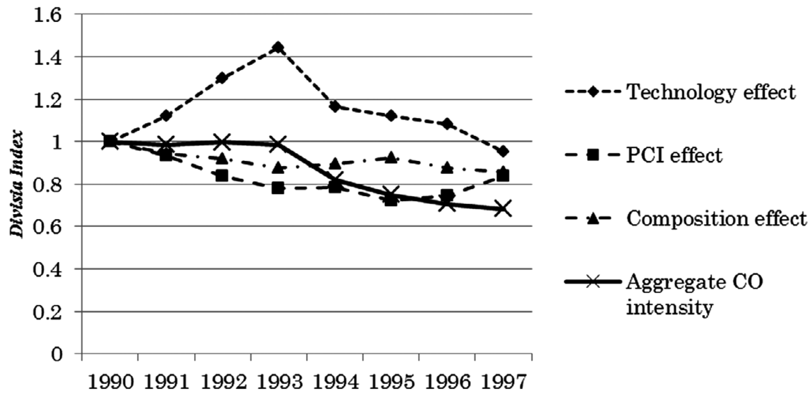

Figure 2. Decomposition of aggregate CO_2 intensity.

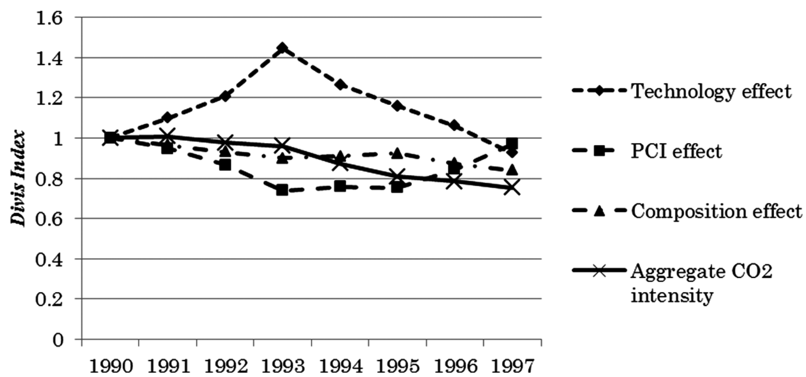

Figure 2 shows that CO_2 follows a similar trend to the study on CO. The aggregate CO_2 intensity was maintained till 1993 but it then followed a declining trend. The reduction in aggregate CO_2 till 1993 was driven by the physical capital intensity effect and the composition effect, especially the physical capital effect. However, from 1993, the technology effect became the main driver for the decline in aggregate CO_2 intensity. Overall, compared to the start of the observation in 1990, the aggregate CO_2 intensity and all three effects had improved. The difference with CO is that the aggregate CO_2 intensity did not decline overall as much as the aggregate CO intensity and the effect of the physical capital intensity was weaker and the composition effect was the main driver behind the improvement.

The results of NO_x depicted in Figure 3 shows a much different trend from the analysis on CO and CO_2 emissions. The main difference was that the aggregate intensity of NO_x consistently declined over the period examined. The main drivers of the decline until 1993 were the physical capital

Figure 3. Decomposition of aggregate NO_x intensity.

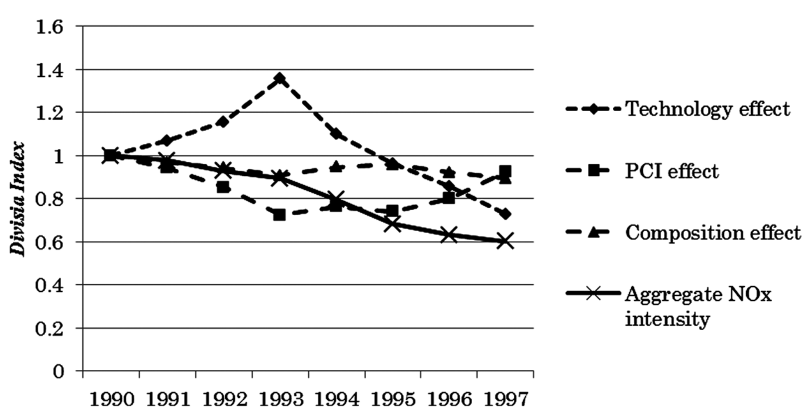

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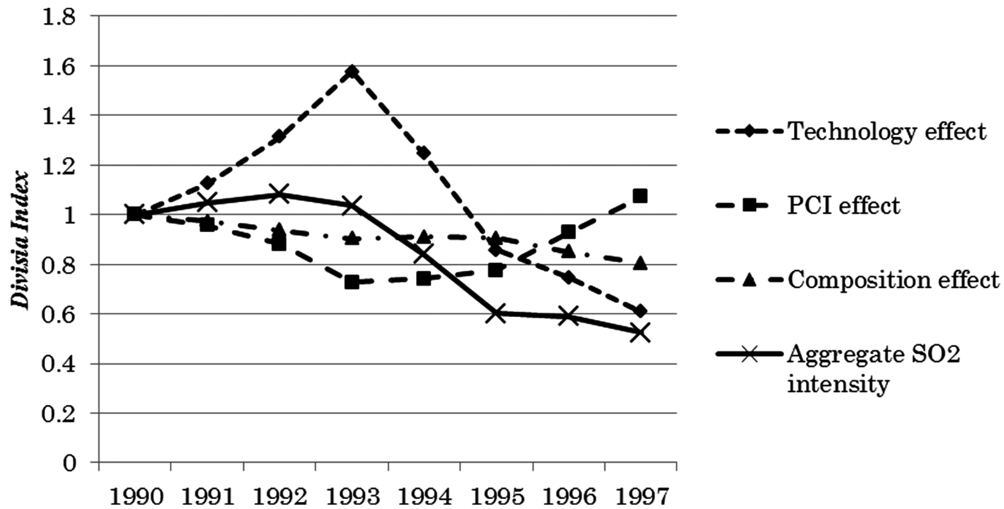
Figure 4. Decomposition of aggregate SO_2 intensity.



intensity effect and the composition effect, especially the physical capital intensity effect. However, from 1993, the main driver of the decline in aggregate NO_x intensity was the technology effect. At the end of the observation period, all of the three effects with the aggregate NO_x intensity had improved compared to the beginning in 1990. A distinction from the previous two analysis is that the results for NO_x showed a far stronger improvement in reducing aggregate pollution intensity and that the technology effect had a stronger influence than on the aggregate CO intensity and CO_2 intensity.

Table 1. The contribution of each sector to total manufacturing pollution

Economic sector	NACE	SO_2 (%)	NO_x (%)	CO (%)	CO_2 (%)
Food and beverages	15	8.05	11.36	3.81	8.37
Tobacco products	16	0.06	0.08	0.03	0.08
Textiles	17	1.82	1.50	0.69	1.73
Clothing manufacture	18	0.56	0.44	0.18	0.38
Leather, luggage and footwear	19	0.10	0.15	0.07	0.13
Timber	20	0.12	1.80	1.51	0.63
Pulp and paper	21	4.56	3.46	1.54	3.96
Publishing and printing	22	0.16	0.78	0.70	0.67
Coke oven and refined petrol prods	23	26.33	13.85	4.32	18.15
Basic chemicals	24	15.21	10.87	6.65	12.19
Rubber products	25	4.52	3.47	1.33	4.08
Non-metallic minerals	26	16.46	24.53	5.95	14.26
Iron and steel	27	16.11	12.56	56.84	25.22
Fabricated metal products	28	0.55	2.18	1.97	1.68
Machinery and equipment	29	0.89	2.11	1.95	1.56
Office machinery, computers	30	0.11	0.11	0.09	0.10
Electrical machinery and apparatus	31	0.70	0.67	0.37	0.65
Radio, television and comms	32	0.32	0.49	0.25	0.37
Medical, and precision instruments	33	0.17	0.40	0.44	0.31
Motor vehicles and trailers	34	0.80	1.87	1.30	1.65
Other transport equipment	35	1.06	1.10	0.82	1.15
Manufacture of other products	36	1.34	6.23	9.18	2.70

Note: Average contribution over the period examined: for UK (1990–1997).

Figure 4 illustrates a slight increase in aggregate SO_2 intensity until 1993 and then shows a declining trend. Until 1993, the negative impact of the technology effect such as the usage of inefficient production techniques played a more dominant role than the positive effects from the physical capital effect and the composition effect. From 1993, the improvements in the technology effect had contributed towards the decline in aggregate SO_2 intensity. Overall, the results of the decline in aggregate pollution intensity for SO_2 were the largest of all of the pollution emissions analysed. Similar to the results of NO_x, the technology effect was the main contributor, but the contribution was larger in reducing the aggregate pollution intensity for SO_2. The SO_2 result was the only one that ended with a negative physical capital intensity effect at the end of the observation period compared to the start.

Tables 1 and 2 provide some insight into the presence of a composition effect for the UK. Table 1 presents each sector's contribution towards the total manufacturing emissions for each pollutant for the UK. Across all pollutants it can generally be seen that the key sectors responsible for the largest contributions are NACE 23 (Coke Oven Products etc.), NACE 24 (Basic Chemicals), NACE 26 (Non-Metallic Minerals) and NACE 27 (Iron and Steel).

Table 2 provides the change in pollution intensities for each sector over the period under observation for the UK. This study shows that the SO_2 intensities have fallen for almost all industries. For the dirty industries, the SO_2 intensities of NACE 24, NACE 26 and NACE 27 have fallen by around 63, 63 and 12%, respectively, over time. With respect to NO_x intensity, it was found that almost all industries had decreased over the period examined as with the case of SO_2 intensity. As for dirty industries, NACE 24, NACE 26 and NACE 27 have fallen during the observed period. With regards to CO

Table 2. The change in pollution intensity 1990–1997

Economic sector	NACE	SO_2/VA (%)	NO_x/VA (%)	CO/VA (%)	CO_2/VA (%)
Food and beverages	15	−72	−60	−71	−31
Tobacco products	16	−31	−14	−13	21
Textiles	17	−75	−34	−19	−31
Clothing manufacture	18	−95	−77	−55	−66
Leather, luggage and footwear	19	−34	−20	−22	−9
Timber	20	−45	17	15	18
Pulp and paper	21	−82	−41	22	−43
Publishing and printing	22	−124	−54	−23	−28
Coke oven and refined petrol prods.	23	8	1	7	27
Basic chemicals	24	−63	−47	−33	−20
Rubber products	25	−89	−55	−58	−47
Non-metallic minerals	26	−63	−47	−48	−31
Iron and steel	27	−12	−5	−11	1
Fabricated metal products	28	−74	−53	−12	−49
Machinery and equipment	29	−91	−65	−44	−56
Office machinery, computers	30	−67	−72	−92	−62
Electrical machinery and apparatus	31	−74	−72	−15	−72
Radio, television and comms	32	−50	−113	−71	−86
Medical, and precision instruments	33	−106	−72	−29	−79
Motor vehicles and trailers	34	−132	−90	−77	−71
Other transport equipment	35	−18	−6	0	0
Manufacture of other products	36	−148	−103	−101	−102

Notes: Average growth over the period examined: UK (1990–1997). In order to remove the influence of the observations for the first and last years of the sample the percentage change is based on the difference between the average of the first two years and the average of the last two years.

intensity, almost all industries have declined over the time period. Dirty industries such as NACE 24, NACE 26 and NACE 27 have also declined during the period. As for CO_2 intensity, although almost all industries have experienced a decline in CO_2 intensity, compared to the other pollution emissions, it had the largest number of industries that increased its pollution intensity. All of the pollution emissions observed showed an increase in pollution intensity for NACE 23, which is a dirty industry.

Next the changes in pollution intensity are further decomposed into changes in physical capital intensities and changes in pollutants physical capital ratio. Table 3 provides the changes in physical capital intensities for each sector in the UK over the period under observation. This study shows that around two third of the industries examined had experienced the decline of physical capital intensity. As for the dirty industries, physical capital intensity for NACE 23 and NACE 26 had increased during the period this study observed, by around 42 and 4%, respectively. On the other hand, physical capital intensity for NACE 24 and NACE 27 has decreased over the period analysed, by around 7 and 17%, respectively.

Table 4 presents the change in pollutants physical capital ratio for each sector in the UK over the period analysed. The results find that, as for SO_2 physical capital ratio, almost all industries have experienced the decline of the index during the period observed. This implies that environmental efficiency for SO_2 in almost all industries have been achieved during the period, including dirty industries such as NACE 23, NACE 24 and NACE 26. However, with regard to NACE 27 which is also a dirty industry, the SO_2 physical capital ratio had increased over the time period examined. NO_x physical ratio in almost all industries has declined over the period, as was seen in the results of SO_2 physical capital ratio. However, a few industries (NACE 27, NACE 28) have experienced an increase of NO_x

Table 3. The change in physical capital intensity 1990–1997

Economic sector	NACE	PCI change rate (%)
Food and beverages	15	−8.4
Tobacco products	16	60.9
Textiles	17	−12.1
Clothing manufacture	18	−10.5
Leather, luggage and footwear	19	−33.2
Timber	20	−17.8
Pulp and paper	21	−6.7
Publishing and printing	22	−2.1
Coke oven products, refined petroleum products, processing of nuclear fuel	23	41.8
Basic chemicals	24	−6.6
Rubber products	25	6.6
Non-metallic minerals	26	3.8
Iron and steel	27	−16.7
Fabricated metal products	28	−20.3
Machinery and equipment	29	−11.0
Office machinery, computers	30	5.7
Electrical machinery and apparatus	31	−8.1
Radio, television and comms	32	40.9
Medical, precision, optical instruments	33	0.4
Motor vehicles and trailers	34	17.3
Other transport equipment	35	−13.7
Manufacture of other products	36	−3.6

Notes: Average growth over the period examined: UK (1990–1997). In order to remove the influence of the observations for the first and last years of the sample the percentage change is based on the difference between the average of the first two years and the average of the last two years.

Table 4. The change in pollutants–physical capital ratio 1990–1997

Economic sector	NACE	SO_2/PC (%)	NO_x/PC (%)	CO/PC (%)	CO_2/PC (%)
Food and beverages	15	−52	−40	−51	−10
Tobacco products	16	−93	−75	−75	−41
Textiles	17	−51	−10	5	−7
Clothing manufacture	18	−54	−37	−15	−26
Leather, luggage and footwear	19	−19	−5	−6	6
Timber	20	−9	53	52	54
Pulp and paper	21	−55	−13	49	−16
Publishing and printing	22	−89	−19	12	7
Coke oven and refined petrol prods	23	−56	−63	−57	−37
Basic chemicals	24	−36	−20	−6	8
Rubber products	25	−56	−21	−24	−14
Non-metallic minerals	26	−45	−29	−30	−13
Iron and steel	27	5	12	6	18
Fabricated metal products	28	−20	1	42	5
Machinery and equipment	29	−56	−30	−9	−21
Office machinery, computers	30	−57	−61	−82	−52
Electrical machinery and apparatus	31	−38	−36	21	−36
Radio, television and comms	32	−13	−77	−34	−49
Medical, and precision instruments	33	−73	−38	4	−45
Motor vehicles and trailers	34	−83	−41	−28	−22
Other transport equipment	35	−30	−17	−11	−12
Manufacture of other products	36	−64	−19	−17	−18

Notes: Average growth over the period examined: UK (1990–1997). In order to remove the influence of the observations for the first and last years of the sample the percentage change is based on the difference between the average of the first two years and the average of the last two years.

physical capital ratio during the time observed. With respect to CO physical capital ratio, around two-third of the industries have experienced a decline of the index over the period, including the dirty industries such as NACE 23, NACE 24 and NACE 26. However, dirty industry NACE 27, which was the largest contributor of CO emission, has experienced the increase of CO physical capital ratio over the time period. Finally, as for CO_2 physical capital ratio, most of the industries have experienced a decline over the period examined, including dirty industries of NACE 23 and NACE 26. On the other hand, the index of NACE 24 and NACE 27, which are also dirty industries, have increased over the period observed. These results suggest that the pollutants physical capital ratio for all pollutants have been effective for NACE 23 and NACE 26. In other words, these industries were able to improve their technology to ones that were less pollution intensive during the time period examined.

4. Conclusion

The results of the decomposition analysis of the four pollution intensities examined showed that the aggregate pollution intensity has been maintained until 1993 and then goes into a declining trend. Until 1993, the decline of aggregate pollution intensity was driven by the composition effect and the physical capital intensity effect, especially the latter. However, from 1993, the technology effect had become the main contributor. All three of the effects have improved for all of the aggregate pollution intensities compared to the start of the observation in 1990, except for the physical capital effect of SO_2. This suggests that either one of the effects was effective towards the decline in aggregate pollution intensities in this analysis. These results suggest that the 1992 Rio Earth Summit which recognised the importance of air quality monitoring, combined with the major environmental statutory frameworks developed in the UK in the early 1990s which provided the foundation in air quality regulations had some influence over the reduction in pollution intensity in the UK (United Nations, 1992). The significant increase in the number of government-funded automatic measurement stations in the UK to monitor air pollution was also seen during this time (Department for Environment Food & Rural Affairs, 2007). Furthermore, in response to the growing concern of environmental risks and damage, in 1992, the UK first published the British Standards (BS) 7750 with the aim to provide a framework for a company's EMS which had inspired the development of the ISO 14000 series in 1996 which then became the global EMS standard. The Eco-Management and Audit Scheme (EMAS), the EU regulation that incorporates the ISO 14001 standard was developed in 1993 for EU member states includes an adoption of an environmental policy, the establishment of an EMS, an environmental audit and an environmental statement (European Commission, 2013). The characteristic of the EMAS is that it requires the disclosure of environmental performance within the environmental report and requires an acceptance of an external audit[1] (Otsuka, 2007). Such focus on EMS with the adoption of the Environment Agency's Pollution Inventory (PI) in the UK aimed to have firms report their emission of air and water pollutants will have raised the awareness of the pollution caused by each firm and industry which may have had an impact on the three effects studied in this analysis to reduce aggregate pollution intensity. The period observed in this study was during a period when economic instruments such as pollution taxes were not effectively implemented in the UK. However, major environmental statutory frameworks to regulate air pollution such as the Environmental Protection Act, the Clean Air Act and the Environment Act and the voluntary programmes such as the BS7750, EMAS and PI were available during this period and the results suggest the effectiveness[2] of these programmes.

The results for the aggregate intensity for CO_2, which is considered a main contributor of global warming, shows minimum decline compared to SO_2 and NO_x. This may imply that direct pollutants respond quicker than indirect pollutants towards improvements. Indirect pollutants such as CO_2 have not showed an inverted U-U curve as in past Environmental Kutznets Curve studies (see Neumayer, 2003). The results of this study appear to support these findings. During the period observed in this study, the UK had not yet entered into emission trading or implemented climate change levies. If such economic instruments were applied, the aggregate CO_2 intensity may have improved as the other pollutants that were studied. The impact of the technology effect on CO_2 seems to be weak and so economic, political and social systems to support the development of technology to reduce CO_2 intensity may have been required, since SO_2 and NO_x during the observed period showed a positive response to the technology effect. As for CO, the results were similar to CO_2 and the technology effect had little impact on improving aggregate pollution intensity compared to the results of SO_2 and NO_x. Analysing the historical trend of the pollution emissions in the UK may provide learning for environmental policies of developing countries. For example, direct and voluntary regulations may be effective in controlling direct pollutants such as SO_2 and NO_x, but indirect pollutants such as CO and CO_2 may require economic instruments included in an integrated environmental policy.

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Notes
1. This is different from the ISO14000 series.
2. Effective voluntary measures may include direct and indirect increase in profit and mitigation of environmental risks.

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