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Structural decomposition of CO_2 emissions in the Slovak economy
Štruktúrna dekompozícia emisií CO2 v slovenskej ekonomike

Michal Habrman

Abstract

The paper examines changes and their causes in CO_2 emissions in Slovak economy. We use the symmetrical commodity-to-commodity input-output tables to identify the most polluting commodities in the sense of both direct and indirect effects. We decompose these changes into the contribution of (1) technological progress in the sense of reducing direct emissions per unit of output, (2) changes in the structure of production described by Leontief inverse and (3) changes in final demand. For our analysis we make use on the availability of symmetric input-output tables for Slovak economy for the years 2000 and 2005 in constant prices of 2000. Our results show increasing emissions in Slovakia by 3,6 %, with significant structural changes. Final demand growth was the main force that increased the emissions, while structural changes helped to erase vast majority of that increase. Interestingly, direct emissions per unit of output did not fall down but even slightly grew up what is in contradiction with similar studies in other countries (e.g. Norway or Austria).

Keywords:

Structural decomposition analysis, Input-output model, CO_2 emissions

JEL classification: C67, Q53

Abstrakt

V práci skúmame zmeny emisií CO_2 a príčiny týchto zmien v slovenskej ekonomike. Pomocou symetrických input-output tabuliek identifikujeme komodity s najväčším znečistením v zmysle priamych a nepriamych efektov. Tieto zmeny rozkladáme na príspevok (1) technologického rozvoja – znižovanie priamej emisnej náročnosti produktu, (2) zmeny v štruktúre produkcie popísanej Leontiefovou inverziou a (3) zmenou v konečnom dopyte. Pre túto analýzu využívame symetrické tabuľky pre slovenskú ekonomiku za roky 2000 a 2005 v stálych cenách roku 2000. Výsledky poukazujú na zvýšenie emisií na Slovensku o 3,6 % s významnými štruktúrnymi zmenami. Rast konečného dopytu bol hlavným zdrojom rastu emisií, kým štruktúrne zmeny negovali veľkú väčšinu tohto nárastu. Priame emisie na jednotku produkcie nepoklesli, ale prekvapivo mierne stúpli, čo je v protiklade s podobnými štúdiami v zahraničí (napr. Nórsko, Rakúsko).

Kľúčové slová:

Štruktúrna dekompozícia, Input-output model, emisie CO_2

JEL klasifikácia: C67, Q53

Content

1 Introduction

The concept of sustainable development became important, both economically and politically, in the face of global environmental changes. Economically, because depletion of natural resources and degradation of environment may threaten future economic development and politically, because policymakers are those who can slow down, eventually stop these negative tendencies and preserve resources for future generations. One of the most severe environmental problem is global warming which is thought to be caused by emission of CO_2 and other greenhouse gases (methane, CO,...).

Global political decisions have been made to lower the carbon dioxide (CO_2) emissions, e.g. Kyoto Protocol, Lisbon Strategy or Europe 2020. The common aim is to reduce the CO_2 emissions. But what shall be the source of reducing emissions? Shall we stop economic growth or even de-growth? Shall we shift to technological processes which replace emission intensive inputs by emission less intensive inputs? Or shall we develop and use technologies which emit less CO_2 with the same technological processes? Structural decomposition analysis may give us an answer to these questions.

In this paper we decompose the changes in CO_2 emissions in Slovakia into three components – (1) technological progress reducing emissions per unit of output while fixing the production „recipies“, (2) structural changes – shift to less emission intensive inputs and (3) final demand growth.

2 The Model

The basic static Leontief model has the form

$$x = (I - A)^{-1}y \qquad (1)$$

In environmentally extended Leontief model we introduce emission matrix X^e into the basic model, such that

$$X^e = \{x^e_{kj}\}$$

Where: k – holds for number of environmental outputs in the analysis (in our case k = 1, which accounts for CO_2 emissions)

j – holds for number of commodities; j = 1,2,....n

Because we analyse only CO_2 emissions, k = 1 and the emission matrix X^e can be rewritten as a vector $x^e = \{x^e_j\}$. Dividing the CO_2 emissions of sector j by the total industry output x_j leads to a vector of direct output coefficients e_j

$$e_j = x^e_j / x_j \qquad \text{with } e_j = \hat{e} \qquad (2)$$

The diagonal matrix of CO_2 emission coefficients $\hat{e}$ shows the direct emissions of each commodity which is generated by producing one unit of output of this commodity.

But it does not show the indirect emissions generated by production of other commodities which are provided as inputs for the final demand.

If we multiply the diagonal matrix of CO_2 emission coefficients $\hat{e}$ by the total requirements matrix L, we obtain the total emissions intensity matrix M_e

$$M_e = \hat{e}L = \hat{e}(I - A)^{-1} \tag{3}$$

The element m^e_{ij} of the matrix M_e illustrates the amount of CO_2 emissions of commodity i generated to produce one unit of commodity j for final use. The column sums of total emissions intensity matrix give the CO_2 multipliers. These multipliers describe the total amount of CO_2 generated throughout the economy to deliver one unit of final demand of the respective commodity.

To calculate the total emissions we multiply the total emissions intensity matrix with the final demand vector

$$x^e = M_e f \tag{4}$$
$$x^e = \hat{e}(I - A)^{-1} f = \hat{e}Lf \tag{4a}$$

Equations (4) and (4a) are the basis for the structural decomposition analysis. We can decompose the total emissions change into the contribution of emission intensity coefficients changes and final demand changes.

2.1 Structural decomposition analysis

Structural decomposition analysis makes it possible to decompose the total amount of a change in some aspect of the economy into contributions made by its various components. Following from (4) the total emissions change x_e can be decomposed into the part associated with changes in technology (in production recipes) – the structural change and changes generated by final demand changes. Both elements can be decomposed further on (see Millar, Blair 2009).

Following from (4a) the initial decomposition can be made into three components – the change in direct emission coefficients ($\Delta\hat{e}$), change in indirect emission coefficients (ΔL) and final demand change (Δf).

For the change in total emissions we derive:

$$\Delta x^e = x^e_1 - x^e_0 = \hat{e}^1 L^1 f^1 - \hat{e}^0 L^0 f^0 \tag{5}$$

The decomposition into various component changes does not have a single solution but is a set of solutions (shown for example in Miller – Blair, 2009). According to Dietzenbacher and Los (1998) we can use an average of the two polar decompositions to get acceptable results. The two polar decompositions in our case are:

$$\Delta x^e = (\Delta\hat{e})(L^0 f^0) + \hat{e}^1(\Delta L) f^0 + \hat{e}^1 L^1 (\Delta f) \tag{6}$$
$$\Delta x^e = (\Delta\hat{e})(L^1 f^1) + \hat{e}^0(\Delta L) f^1 + \hat{e}^0 L^0 (\Delta f)$$

And the average of these polar decompositions:

$$\Delta x^e = \frac{1}{2}(\Delta\hat{e})(L^0 f^0 + L^1 f^1) + \frac{1}{2}[\hat{e}^1(\Delta L)f^0 + \hat{e}^0(\Delta L)f^1] + \frac{1}{2}(\hat{e}^0 L^0 + \hat{e}^1 L^1)(\Delta f) \tag{7}$$

In the next step we can further decompose the change in final demand into the effect of change in final-demand product mix (a shift among commodities with various emission intensity; ΔB), change in final-demand distribution (shift among final-demand categories; Δd) and change in final-demand total level (Δ*f*). To do so, we just simply enlarge our decomposition equation:

$$\begin{aligned}\Delta x^e = {} & \frac{1}{2}(\Delta\hat{e})(L^0 B^0 d^0 f^0 + L^1 B^1 d^1 f^1) \\ & + \frac{1}{2}[\hat{e}^0(\Delta L)B^1 d^1 f^1 + \hat{e}^1(\Delta L)B^0 d^0 f^0] \\ & + \frac{1}{2}[\hat{e}^0 L^0(\Delta B)d^1 f^1 + \hat{e}^1 L^1(\Delta B)d^0 f^0] \\ & + \frac{1}{2}[\hat{e}^0 L^0 B^0(\Delta d)f^1 + \hat{e}^1 L^1 B^1(\Delta d)f^0] \\ & + \frac{1}{2}(\hat{e}^0 L^0 B^0 d^0 + \hat{e}^1 L^1 B^1 d^1)(\Delta f)\end{aligned} \tag{8}$$

Where: Δx^e – vector of emission change (57x1)
$\hat{e}$ – diagonal matrix of direct emissions per unit of output (57x57)
L – Leontief inverse (57x57)
B – matrix of final demand product mix (57x4)
d – vector of final demand distribution (4x1)
f – scalar of total final demand level

2.2 Data

For the structural decomposition analysis (SDA) we make use of symmetrical input-output tables in dimension commodities by commodities for the years 2000-2005. We took the advantage of the tables being in constant prices of the year 2000. Due to this fact the results of our decomposition will not be affected by the change in prices. The input-output data are provided by the Statistical Office of Slovak republic. The CO_2 emissions are provided by Eurostat. They are structured according to industries (NACE activities) and data are provided in thousands of tons.

However there is apparent inconsistency in the data, as the symmetrical input-output table is classified according to commodities but CO_2 data are provided in industry classification. To solve this problem we can transform the input-output table into industry by industry structure, use the make-use approach (as has been done by Stocker and Luptáčik, 2009) or transform the CO_2 data into commodity classification. We decided for the latter one. The main reason we do so is the fact that we do not dispose of use tables in basic prices and therefore cannot derive industry by industry input-output tables, nor we can employ the make-use approach. Even if we had use tables in basic prices, we would need them in constant prices.

2.3 Transformation of CO_2 data

We decided to transform the CO_2 data from industry classification to commodity classification. This cannot be done simply by identifying each industry with corresponding commodity (e.g. agriculture with agricultural products) because each industry produces besides the primary products also secondary products (e.g. agriculture produces also food and beverages, wood products, provides construction services, wholesale trade, retail services, etc.) which cannot be neglected. Therefore we decided to redistribute secondary production (and corresponding CO_2 emissions) to their respective primary sectors.

To do so, we create matrix C:

$$C = V^T \hat{x}^{-1} \tag{9}$$

Matrix C is called the product mix matrix, or sometimes the commodity mix matrix and has dimensions com x ind. Matrix V^T is defined as supply matrix in dimension commodity by industry (com x ind). Vector x is the vector of total production of industries. We have defined $c_{ij} = v^T_{ij}/x_j$ (each element in column j of V^T is divided by the j-th column sum x_j), so that c_{ij} denotes the fraction of industry j output that was in the form of commodity i (industry output proportions).

Afterwards we multiply the product mix matrix C by vector of total CO_2 emissions output classified by industries x^e_j :

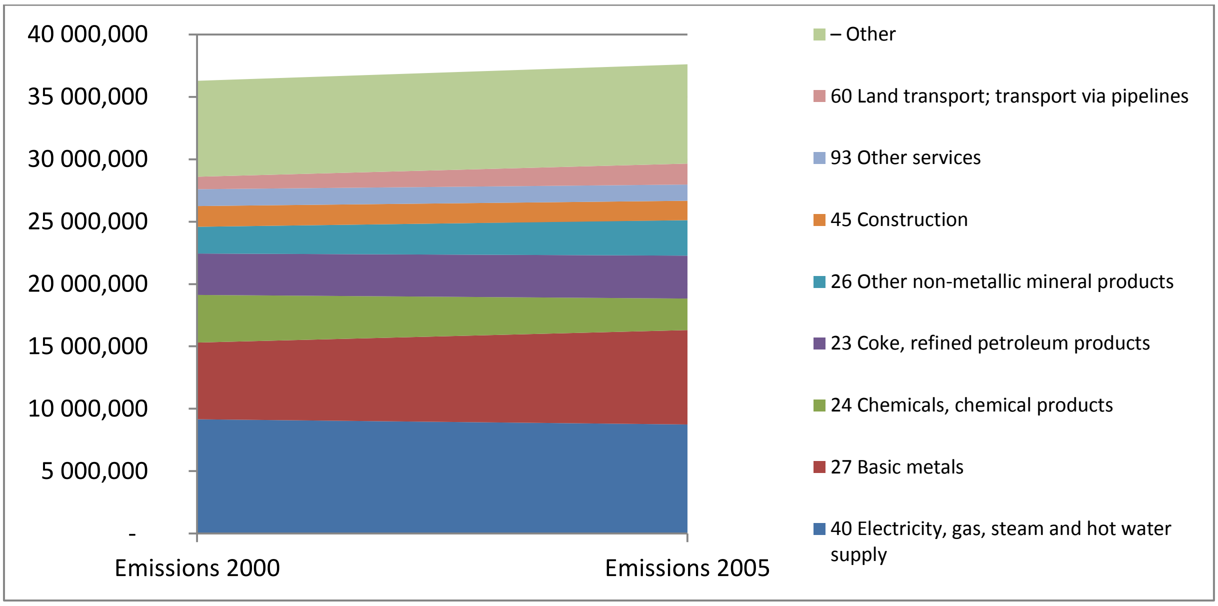
$$x_i^e = Cx_j^e \tag{10}$$

Thanks to this simple procedure we get the total emissions in the commodity structure. Have in mind however that this has been accomplished by the industry technology assumption where we expect that each commodity is produced by the same production recipe within given industry (in our case no matter if a farmer produces agricultural products or wood products, the emission coefficient per unit of output will be the same).

3 Results

The total amount of CO_2 emissions emitted in Slovakia grew from 36,3 mil. tons to 37,6 mil. tons during 2000-2005 period which corresponds to a 3,6 % change. Commodities that contributed to CO_2 emissions by the largest portion are portrayed in figure 1, with electricity, gas and hot water production and basic metals production being the largest emitters.

Figure 1: Development of total CO_2 emissions per commodity between 2000 and 2005, in 1,000 t



Source: Own elaboration

The largest absolute increases in CO_2 emissions are observed in production of basic metals, other non-metallic mineral products and land transport. On the other side, large decreases are observed in production of chemicals and electricity, gas and hot water, as we can see in figure 2.

Figure 2: The largest changes in emissions among commodities

NACE	Commodity	Total change 1,000 tons	NACE	Commodity	Total change 1,000 tons
27	Basic metals	1 416,910	24	Chemical products and man-made fibres	-1291,130
26	Other non-metallic mineral products	699,732	40	Electricity, gas, steam and hot water supply	-416,064
60	Land transport; transport via pipelines	680,451	21	Pulp, paper and paper products	-222,591
28	Fabricated metal products	157,413	15	Food products and beverages	-199,586
23	Coke, refined petroleum products	120,679	45	Construction	-104,878

Source: Own elaboration

Changes in CO_2 emissions can be caused by (1) technological progress reducing emissions per unit of output while fixing the production „recipes“, (2) structural changes – shift to less emission intensive inputs and (3) final demand growth. This is the core of the paper – to discover the reasons behind the change of emissions. Maybe a huge decrease in CO_2 emissions in producing particular commodity is caused by a sharp fall in final demand for this particular commodity or by a fall in intermediate consumption by other commodities and the emissions per unit of output may even rise and we do not see that on first sight. And this holds also vice versa.

Thanks to structural decomposition analysis (SDA) we may decompose the total changes in emissions into the contribution of (1) technological progress in the sense of reducing direct emissions per unit of output, (2) changes in the structure of production described by Leontief inverse and (3) changes in final demand. Figure 3 presents the result of SDA. Total emissions increased by 1,3 mil. tons which accounts for a 3,6 % change with respect to total emissions of year 2000. Final demand increase was the main force that increased the emissions – by 8,6 mil. tons (23,7%). Significant structural changes (embodied in Leontief inverse) decreased total emissions by more than 7,6 mil. tons (-21,1%). Interestingly, direct emissions per unit of output did not fall down but even slightly grew up (391 thousand tons, 1,1%). That is a surprising figure and is in sharp contradiction with our assumptions and similar studies in other countries (Stocker and Luptacik, 2009; Yamakawa and Peters 2011).

Figure 3: Results of SDA

	Total	Direct emissions	Leontief inverse	Final demand growth
Absolute change (1,000 t)	1323,6	390,9	-7670,7	8603,5
Relative to beginning period emissions - 36,7 mil. t	3,6%	1,1%	-21,1%	23,7%

Source: Own elaboration

A more detailed insight into the results of SDA (figure 4) reveals the causes behind such a surprising increase in direct emissions. The increase is enhanced mainly by basic metals, land transport and other non-metallic mineral products. However to be correct, we have to mention an obviously unrealistic jump in direct CO_2 emissions in land transport and metal ores that might be caused rather by rearrangements of data among different commodities by the statistical authority than by truly increase of emission intensity.

Figure 4: Commodities with biggest direct emission change

NACE	Commodities	Effect of direct emission change	Direct CO2 intensity (2000)	Direct CO2 intensity (2005)	Direct CO2 intensity change
		1,000 t	***1,000 t / mil.€***	***1,000 t / mil.€***	***relative change***
27	Basic metals	1564,502	1,669	2,099	25,7%
60	Land transport; transport via pipelines	1029,475	0,209	0,452	115,9%
26	Other non-metallic mineral products	640,659	1,765	2,286	29,6%
23	Coke, refined petroleum products	110,613	1,525	1,576	3,3%
13	Metal ores	107,453	2,714	7,876	190,2%
	...				
34	Motor vehicles, trailers and semi-trailers	-299,447	0,104	0,042	-59,9%
24	Chemicals, chemical products	-461,238	1,722	1,487	-13,7%
45	Construction	-469,198	0,285	0,213	-25,1%
93	Other services	-488,678	6,025	4,193	-30,4%
40	Electricity, gas, steam and hot water supply	-550,937	1,676	1,576	-6,0%

Source: Own elaboration

3.1 Digging deeper into Δf

The effect of final demand increase may be further decomposed into the effect of change in final-demand product mix (a shift among commodities with various emission intensity; ΔB), change in final-demand distribution (shift among final-demand categories; Δd) and change in final-demand total level (Δ*f*). Our assumption was that final demand shifted from consumption of emission intensive products towards consumption of emission less intensive products (as happened in case of intermediate consumption) and thus the effect of change in final demand total level would be magnified in comparison with effect of final demand growth as shown in figure 3.

Figure 5: Results of extended SDA

	Total	Direct emissions	Leontief inverse	Final demand product mix	Final demand distribution	Final demand level
Absolute change, in 1,000 t.	1323,63	390,88	-7670,71	-2553,54	1033,43	10123,56
Relative change, (beginning period - 36,7 mil. t.)	3,6%	1,1%	-21,1%	-7,0%	2,8%	27,9%

Source: Own elaboration

The results of extended structural decomposition analysis are in line with our assumptions. The shift in final demand product mix contributed to the decrease of CO_2 emissions by some 2,5 mil.t. which accounts for a 7% decrease in total CO_2 emissions. The final demand level change accounts for a 10 mil.t. increase (28% relative to beginning CO_2 level) and final demand distribution change increased emissions by 1 mil.t. (2,8%).

4 Conclusion

We performed a structural decomposition analysis of CO_2 emissions in Slovakia for the period 2000-2005. We used the symmetrical input-output table in constant prices of 2000. In addition we transformed the CO_2 data from industry classification into commodity classification using the industry technology assumption. The quantitative results show that the total emissions increased by 3,6%, while final demand level increase was the main contributor (28% increase relative to 2000 data) On the other side changes in intermediate consumption and final demand consumption decreased the emissions by 21% and 7%, respectively. The direct emission coefficients per unit of output increased during this time and increased the total emissions by 1%. This is a surprising fact that direct emission coefficients did not lower during this period but even slightly grew up which is in contradiction with our assumptions and similar empirical studies from other countries.

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