Federal
Planning Bureau
Economic analyses and forecasts

WORKING PAPER 5-13

Does Offshoring Contribute to Reducing Air Emissions? Evidence from Belgian Manufacturing

May 2013

Bernhard Michel, bm@plan.be

Avenue des Arts 47-49 – Kunstlaan 47-49
1000 Brussels

E-mail: contact@plan.be
http://www.plan.be

Federal Planning Bureau

The Federal Planning Bureau (FPB) is a public agency.

The FPB performs research on economic, social-economic and environmental policy issues. For that purpose, the FPB gathers and analyses data, examines plausible future scenarios, identifies alternatives, assesses the impact of policy measures and formulates proposals.

The government, the parliament, the social partners and national and international institutions appeal to the FPB's scientific expertise. The FPB provides a large diffusion of its activities. The community is informed on the results of its research activities, which contributes to the democratic debate.

The Federal Planning Bureau is EMAS-certified and was awarded the Ecodynamic Enterprise label (three stars) for its environmental policy

url: http://www.plan.be
e-mail: contact@plan.be

Publications

Recurrent publications:
Outlooks
Short Term Update

Planning Papers (last publication):
The aim of the Planning Papers is to diffuse the FPB's analysis and research activities.

113	Visions à long terme de développement durable. Concepts, applications et élaboration Task force développement durable - March 2013

Working Papers (last publication):

4-13	Analyse de l'adéquation de la production électrique en Belgique à l'horizon 2030 - Analyse basée sur les scénarios du projet d'EPE2 Dominique Gusbin - April 2013

Responsible publisher: Henri Bogaert
Legal Deposit: D/2013/7433/15

Federal Planning Bureau
Avenue des Arts 47-49, 1000 Bruxelles
phone: +32-2-5077311
fax: +32-2-5077373
e-mail : contact@plan.be
http://www.plan.be

Does Offshoring Contribute to Reducing Air Emissions? Evidence from Belgian Manufacturing

May 2013

Bernhard Michel, bm@plan.be

Abstract - Since the mid-90's, production-related air emissions in Belgian manufacturing have been reduced substantially and it can be shown that the pace of the reduction has been fastest for domestic intermediates. It is widely debated whether offshoring has played a role in this reduction by replacing domestic intermediates by imported intermediates. This paper develops a decomposition analysis to measure the contribution of offshoring – the share of imported intermediates in total intermediates – to the fall in air emission intensities for domestic intermediates. This decomposition analysis reveals that 27% of the fall in the intensity of greenhouse gas emissions, 20% of the fall in the intensity of acidifying emissions and 20% of the fall in the intensity of tropospheric precursor emissions in Belgian manufacturing between 1995 and 2007 can be attributed to offshoring.

Jel Classification - F18, Q53

Keywords - trade in intermediates, offshoring, air emissions, decomposition analysis

Table of contents

List of tables

List of figures

Executive summary

Since the mid-nineties, production-related air emissions in Belgian manufacturing have been reduced substantially. Figures from the Belgian Air Emission Accounts show that the fall amounts to 14% for greenhouse gas (GHG) emissions, 35% for acidifying (ACID) emissions and 33% for tropospheric precursor (TOFP) emissions between 1995 and 2007. It can be shown that the pace of the reduction has been fastest for the production of goods used as intermediates. This relates to the widely debated issue of whether offshoring has played a role in this reduction. Indeed, as production processes become ever more fragmented internationally, domestic intermediates are replaced by imported intermediates and the share of imported intermediates in total intermediates, which is also called offshoring, rises. One of the consequences of offshoring may be that less air pollution is emitted for the production of intermediates in Belgium leading to a reduction in total manufacturing emissions. This may occur regardless of the underlying cause of offshoring. In other words, even if the motivation for offshoring is not related to air pollution, offshoring may still contribute to reducing production-related air emissions in Belgium.

This paper develops a decomposition analysis to measure the reduction in emission intensities in the manufacturing sector that can be attributed to offshoring. Emission intensities are measured as emissions per unit of output. The decomposition splits changes in emission intensities into four terms: a *technique effect*, which measures the contribution of a change in the production technology, an *efficiency effect*, which measures the contribution of improvements in the efficiency in the use of intermediates, an *offshoring effect*, which measures the contribution of the substitution of imported for domestic intermediates, and an *industry composition effect*, which accounts for shifts in output between industries. The emission intensities and the terms of the decomposition for the three types of air emissions (GHG, ACID and TOFP) are calculated based on data for 23 manufacturing industries from two datasets compiled at the Federal Planning Bureau: the Air Emission Accounts and a time series of constant price supply-and-use tables. According to the results of the decomposition, changes in technology (the technique effect) make by far the largest contribution to the fall in emission intensities for all three types of air emissions in the Belgian manufacturing sector. The results also show that 27% of the fall in the intensity of greenhouse gas emissions and 20% of the fall in the intensity of respectively acidifying emissions and tropospheric precursor emissions in Belgian manufacturing between 1995 and 2007 can be attributed to the growing use of imported intermediates (the offshoring effect).

Synthèse

Depuis le milieu des années 90, les émissions atmosphériques liées à la production dans l'industrie manufacturière belge ont sensiblement diminué. Les statistiques sur les émissions atmosphériques pour la Belgique montrent que la baisse a atteint 14 % pour les émissions de gaz à effet de serre (GES), 35 % pour les émissions de substances acidifiantes (ACID) et 33 % pour les émissions des précurseurs de l'ozone troposphérique (TOFP) au cours la période 1995-2007. Ces statistiques permettent également de montrer que la baisse a été plus rapide dans la production de biens utilisés comme biens intermédiaires. Ceci renvoie à la question largement débattue de la contribution des délocalisations à la baisse des émissions atmosphériques. Suite à la fragmentation internationale toujours plus poussée des processus de production, les biens intermédiaires issus de la production domestique sont remplacés par des biens intermédiaires importés et la part des biens intermédiaires importés dans le total des biens intermédiaires, qui est souvent utilisée comme mesure des délocalisations, augmente. On peut supposer que ces délocalisations contribuent à une baisse des émissions atmosphériques liées à la production de biens intermédiaires en Belgique et, partant, à une baisse des émissions totales de l'industrie manufacturière, indépendamment des motifs sous-jacents pour ces délocalisations. En d'autres termes, même si les délocalisations ne sont pas motivées par des considérations liées aux émissions atmosphériques, elles peuvent néanmoins contribuer à les réduire.

La présente étude propose une analyse de décomposition pour mesurer la contribution des délocalisations à la baisse d'intensité en émissions dans l'industrie manufacturière. L'intensité en émissions est mesurée comme la quantité d'émissions par unité d'output. Les changements de l'intensité en émissions sont décomposés en quatre termes : un *effet technologique* qui mesure la contribution de changements dans la technologique de production, un *effet d'efficacité* qui mesure la contribution d'une plus grande efficacité dans l'utilisation des biens intermédiaires, un *effet de délocalisation* qui mesure la contribution de la substitution de biens intermédiaires domestiques par des importations et un *effet de composition* qui intègre les modifications dans la structure de la production. Les données pour le calcul des intensités en émissions et des termes de la décomposition proviennent de deux bases de données du Bureau fédéral du Plan : les comptes des émissions atmosphériques, d'une part, et une série temporelle de tableaux des ressources et des emplois à prix constants, d'autre part. L'analyse porte sur les trois types d'émissions atmosphériques (GES, ACID et TOFP) pour 23 branches d'activité manufacturières et couvre la période 1995-2007. Il en ressort que ce sont les changements de technologie de production (effet technologique) qui, de loin, contribuent le plus à la baisse de l'intensité en émissions des trois types de polluants atmosphériques. Les résultats montrent également que 27 % de la baisse d'intensité en émissions de gaz à effet de serre, 20 % de celle en émissions de substances acidifiantes et 20 % de celle en émissions de précurseurs de l'ozone troposphérique proviennent d'une augmentation des importations de biens intermédiaires (effet de délocalisation).

Synthese

Sinds midden de jaren 90 zijn de productiegebonden luchtemissies in de Belgische verwerkende nijverheid aanzienlijk gedaald. Volgens cijfers van de Belgische luchtemissierekeningen bedraagt die reductie 14% voor broeikasgasemissies (BKG), 35% voor emissies van verzurende gassen (ACID) en 33% voor de uitstoot van troposferische precursoren (TOPF) over de periode 1995-2007. Er kan aangetoond worden dat de daling het sterkst was voor emissies toegewezen aan binnenlands geproduceerde intermediaire goederen. Dat houdt verband met de vaak gevoerde discussie over de rol die het fenomeen van offshoring hierin speelt. Naarmate productieprocessen internationaal steeds meer worden gefragmenteerd, worden binnenlandse intermediaire goederen immers vervangen door geïmporteerde en stijgt het aandeel van die laatste in het totale intermediaire verbruik (offshoring). Een mogelijk gevolg van offshoring bestaat erin dat de uitstoot van luchtvervuiling bij de productie van intermediaire goederen in België afneemt, waardoor de totale emissies in de verwerkende nijverheid dalen, ongeacht de onderliggende oorzaak van offshoring. Anders gezegd, zelfs indien de reden voor offshoring geen verband houdt met luchtvervuiling, kan offshoring nog steeds bijdragen tot de vermindering van productiegebonden luchtemissies.

Deze paper ontwikkelt een decompositie-analyse om de daling van de emissie-intensiteit in de verwerkende nijverheid te meten die kan worden toegeschreven aan offshoring. De emissie-intensiteit wordt gemeten als de hoeveelheid uitstoot per eenheid productie. Die analyse splitst de veranderingen in emissie-intensiteit op in vier effecten: een *technologisch effect*, dat de bijdrage van veranderingen in de productietechologie meet, een *efficiëntie-effect*, dat de bijdrage van de verbeterde efficiëntie in het gebruik van intermediaire goederen meet, een *offshoring effect*, dat de bijdrage van de substitutie van binnenlandse goederen door ingevoerde intermedaire goederen meet en een *industrie-compositie-effect*, dat de verschuivingen in output tussen industrieën weergeeft. De emissie-intensiteiten en de decompositie-termen voor de drie types van luchtemissies (BKG, ACID en TOPF) worden berekend op basis van data voor 23 bedrijfstakken van de verwerkende nijverheid, afkomstig van twee databanken die zijn opgesteld op het Federaal Planbureau: de luchtemissierekeningen en een tijdreeks van aanbod- en gebruikstabellen tegen constante prijzen. Volgens de resultaten van de decompositie-oefening leveren de technologische veranderingen (technologisch effect) veruit de grootste bijdrage tot de daling van de emissie-intensiteit voor de drie types van luchtemissies in de Belgische verwerkende nijverheid. De resultaten tonen ook dat het toenemend gebruik van ingevoerde intermediaire goederen (offshoring-effect) verantwoordelijk is voor 27% van de daling in intensiteit van broeikasgasemissies en voor 20% van de daling in intensiteit van verzurende emissies en troposferische precursoren in de Belgische verwerkende nijverheid tussen 1995 en 2007.

1. Introduction

Production-related air emissions by the manufacturing sector in Belgium have fallen substantially since the mid-1990's. Figures from the Belgian Air Emission Accounts (AEA, Janssen and Vandille, 2011) show that the fall amounts to 14% for greenhouse gas (GHG) emissions, 35% for acidifying (ACID) emissions and 33% for tropospheric precursor (TOFP) emissions between 1995 and 2007.[1] Air pollution from manufacturing is emitted not only for producing domestically consumed final goods and exports but also for producing intermediate goods, i.e. goods that are used in the production process of downstream industries. The level of air emissions for the production of goods for domestic intermediate use – in short: emissions for domestic intermediates – can be estimated by combining the AEA with supply-and-use tables (SUT) and making the assumption that air pollution emitted in the production of a good does not depend on its use, i.e. is the same whether it is delivered for domestic intermediate use, domestic final use or exports. For Belgium, it turns out that over the period 1995 to 2007, air emissions by the manufacturing sector for the production of goods for domestic intermediate use have been reduced at a faster pace than overall manufacturing air emissions: 28% for GHG, 45% for ACID and 42% for TOFP.2 As a corollary, this implies that air emissions for the production of domestically consumed final goods and exports have been reduced at a below average rate.

The strong decrease in emissions for domestic intermediates in manufacturing deserves some further investigation. This may be to a large extent user-driven. As pointed out in Wiedmann et al. (2010, p.20), there is "increasing emphasis on the idea that companies take some responsibility for production-related impacts of the goods they sell or use". The focus in this paper is on the latter, i.e. goods that are being used. Regarding air emissions for domestic intermediates, it seems particularly important to recognise the impact of decisions made by users as they tend to be less dispersed than final consumers giving greater weight to their purchasing decisions. Among the user-related factors that contribute to reducing emissions for domestic intermediates, three are particularly worth mentioning. The first is technology, which may be at the origin of the reduction as cleaner production processes become implemented. This may be driven by demand for cleaner intermediates by downstream industries pushing producers into adopting cleaner technologies. Second, a compositional effect related to the idea expressed in Wiedmann et al. (2010) may play a role. In order to reduce the production-related emissions of the goods they use, companies may switch to less emission-intensive intermediates, i.e. modify the intermediate input composition of their production. Third, trade may also be a means for decreasing emissions for domestic intermediates. Instead of switching from dirty to clean intermediates, companies may leave their intermediate input composition unchanged, but switch from domestic to foreign suppliers. Replacing intermediates sourced from domestic suppliers by imported intermediates directly implies a reduction in air emissions for domestic intermediates.

The aim of this paper is to take a closer look at air emissions for domestic intermediates by the manufacturing sector and to measure whether and to what extent the above-mentioned factors contribute to

---

[1] For GHG emissions, this is in line with the European Union (EU) average. According to data published by the Statistical Office of the European Union (Eurostat), the level of manufacturing GHG emissions has decreased in the European Union as a whole (-12%) and in most member states during this period.

[2] Emissions for domestic intermediates account for respectively 19%, 17% and 20% of total emissions of GHG, ACID and TOFP in Belgian manufacturing.

reducing these emissions. In this context, the focus is on the role played by trade in intermediates. For this purpose, a decomposition of the change in emissions for domestic intermediates is developed. It is applied using data from the AEA for the three air emission indicators GHG, ACID and TOFP and a time-series of SUT for Belgium over the period 1995-2007.

By paying specific attention to the influence of imports of intermediates on domestic air emissions, this paper addresses an issue that appears as particularly relevant given the changing nature of international trade. As a consequence of the rise of global value chains and the growing international fragmentation of production processes in recent decades, trade in intermediates has become increasingly important.[3] The share of imported intermediates in total intermediates is on the rise in manufacturing. This is generally referred to as offshoring in the literature.[4] Although there are several potential determinants of offshoring, among which the perspective of avoiding polluting air emissions, this paper considers total offshoring rather than offshoring that only serves to reduce air emissions. The purpose of the decomposition analysis developed here is to measure to what extent replacing domestic intermediates by imported intermediates – i.e. offshoring whatever its underlying cause – contributes to reducing emissions in manufacturing.

It is the specific focus on trade in intermediates and user-driven aspects that is novel in this paper compared to the literature on the impact of trade on air emissions. One strand of this literature has adopted the decomposition pioneered by Grossman and Krueger (1991) according to which changes in manufacturing emissions are decomposed into scale, technology and composition effects. In this framework, the traditional approach is to consider that trade affects emissions through the composition effect as it reallocates activities across countries. This approach has been applied to US manufacturing emissions of four air pollutants in Levinson (2009) and to worldwide sulphur dioxide emissions in Grether et al. (2010). In both papers, the contribution of trade to lowering manufacturing emissions is found to be small. The channel for the impact of trade on emissions is different in the decomposition developed here: as it puts the emphasis on imported intermediates, trade contributes to changes in emissions through the technology effect. This is in line with the theoretical model in Antweiler et al. (2001), which shows that trade influences pollution not only through the composition effect, but also through the technology effect. In their empirical analysis, Antweiler et al.(2001) find that trade lowers pollution through the technology effect. However, this result pertains to pollution concentrations rather than emissions.

In parallel to these decomposition analyses, there is also a large and fast growing number of papers, which examine the balance of emissions embodied in trade using input-output (IO) models and data. The aim in this strand of the literature is to measure the relative emission content of exports and imports, thereby showing to what extent countries shift emissions associated with their consumption abroad (Peters and Hertwich, 2008).[5] According to Ahmad and Wyckoff (2003) and Nakano et al.

---

[3] Early discussions of this trend underpinned with data can be found in Yeats (2001) and Hummels et al. (2001). More recently, Johnson and Noguera (2012) provide a long term perspective of the international fragmentation of production processes and the composition of international trade since the 1970's.

[4] This is documented for OECD countries over 1995-2005 in De Backer and Yamano (2012) and for Belgium over 1995-2007 in Hertveldt and Michel (2012).

[5] Wiedmann et al. (2007), Peters (2008) and Serrano and Dietzenbacher (2010) contain methodological discussions and an overview of previous papers on the balance of emissions embodied in trade.

(2009), this balance is negative for OECD countries for carbon dioxide emissions in 1995 and 2000, which implies that, on average, OECD countries import more emissions-intensive goods than they export. Compared to this strand of the literature, the analysis here specifically considers trade in intermediates as a means of replacing domestically sourced inputs and it assesses the contribution of this to changes in emissions.

This paper is organised as follows. The next chapter provides more detail on the data. Chapter 3 presents trends in air emissions, while chapter 4 develops the decomposition. Results are reported in chapter 5 and conclusions are drawn in chapter 6.

2. Data sources

2.1. Air Emission Accounts

The Air Emission Accounts (AEA) for Belgium are compiled by the Federal Planning Bureau (FPB) as an environmental satellite account of the national accounts (NA). They contain data on 15 types of pollutant air emissions that are listed in Appendix Table A1. Methods of compilation and data are described in Janssen and Vandille (2011). Compatibility with the NA is provided for by the method. The industry coverage is 2-digit of the NACE Rev.1.1 classification. For the purpose of the analysis in this paper, data for the years 1995-2007 have been used.

The majority of the 15 types of air emissions in Table 1 have been aggregated into three standard composite indices according to the type of environmental damage they cause. This is explained in detail in Janssen and Vandille (2011).

- The greenhouse gas index (tonnes of CO_2-equivalents):

  $GHG = 1000*CO_2 + 310*N_2O + 21*CH_4 + PFC + SF_6 + HFC$

- The acidification indicator (tonnes of H+-equivalents):

  $ACID = 0.03125 * SO_2 + 0.021739 * NO_x + 0.058824 * NH_3$

- The tropospheric ozone forming potential indicator (tonnes of NMVOC equivalents):

  $TOFP = 1.22 * NO_x + NMCOV + 0.11 * CO + 0.014 * CH_4$

These three composite air emission indicators are used in this paper.

2.2. Supply-and-Use Tables

A time series of constant price supply-and-use tables (SUT) in current and constant prices has been assembled for Belgium at the FPB. The tables cover approximately 120 industries and 320 product categories for the years 1995 to 2007. They have been revised and updated so as to respect the 2010 vintage of the NA, which makes them comparable across years. A description of the compilation method can be found in Avonds et al. (2012). Moreover, the tables have been deflated with separate price indices for domestic output and imports. The base year is 2005. Finally, the dataset contains use tables of imports that have been compiled according to the specific method described in Van den Cruyce (2004).

3. Trends in air emissions

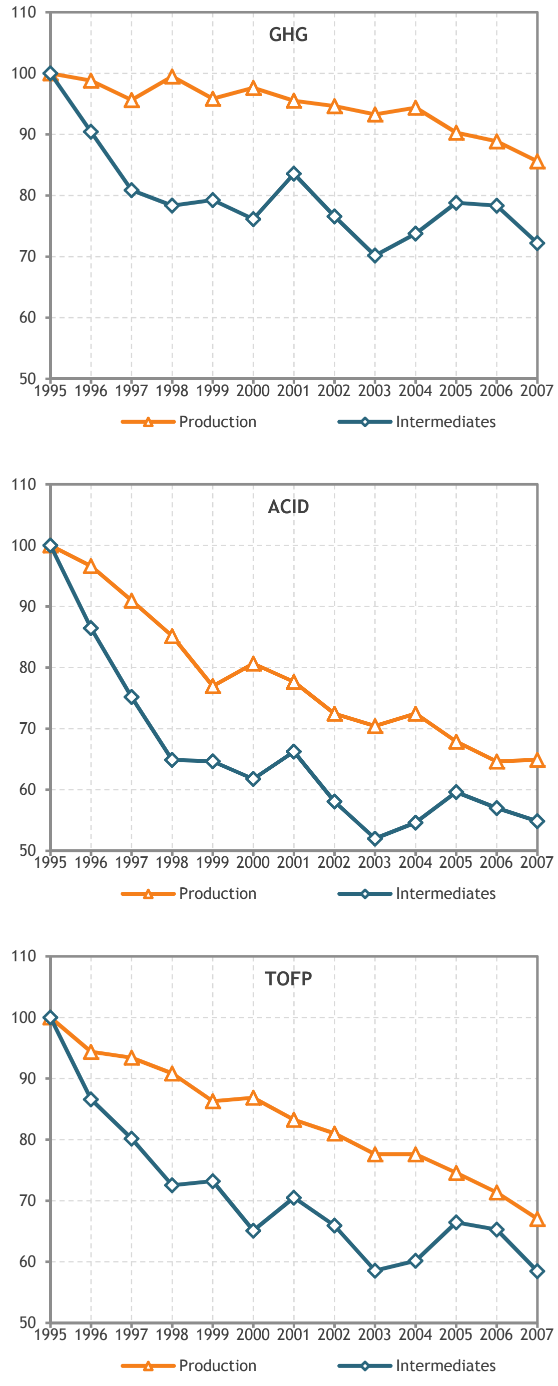
For matrix, vector and scalar notation, this chapter and the next one follow the notation defined in Serrano and Dietzenbacher (2010, p.2225). "Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A diagonal matrix with the elements of any vector on its main diagonal and all other entries equal to zero is indicated by a circumflex." Moreover, k (1,...,K) is used as index for industries and j (1,...,J) as index for products. The k or j subscript added to share, intensity or output vectors indicates whether they are by industry or by product. For emissions as well as intensities, the d superscript indicates that they pertain to domestic intermediates. For shares, d for domestic intermediates, z for total intermediates and y for output are used as superscripts. They may be used as single superscripts for vectors of shares in a total or as double superscripts for vectors or matrices of shares of the variable indicated by the first letter in the variable indicated by the second letter, e.g. shares of domestic intermediates (d) in total intermediates (z).

The compatibility of the AEA with the NA makes it possible to combine them with the dataset of SUT and compute emissions for domestic intermediates for the three above-mentioned aggregate indicators (GHG, ACID, TOFP). These will henceforth be referred to as emissions for domestic intermediates. The following data are needed for the computation: emissions of either GHG, ACID or TOFP by industry from the AEA ($\mathbf{e_k}$), output by industry and product ($\mathbf{Y}$) from the supply table, and domestic intermediate inputs by industry and product ($\mathbf{Z^d}$) from the use table for domestic production. The dimension of $\mathbf{e_k}$ is (Kx1) and that of $\mathbf{Y}$ and $\mathbf{Z^d}$ is (JxK). The computation of emissions for domestic intermediates (e^d) is then done in several steps. First, emission intensities for total production by industry ($\mathbf{a_k}$) are obtained by dividing emissions by output for each industry: $\mathbf{a_k} = (\hat{\mathbf{y}}_\mathbf{k})^{-1}\mathbf{e_k}$ where $\mathbf{y_k} = \mathbf{Y}'\mathbf{i_j}$ and $\mathbf{i_j}$ represents a (Jx1) vector of ones. It must be emphasized that as the data used come from SUT rather than symmetric IO tables, emissions by product ($\mathbf{e_j}$) are not equivalent to emissions by industry ($\mathbf{e_j} \neq \mathbf{e_k}$) due to secondary production. Therefore, as a second step, emissions by product are computed by multiplying industry-level output values of a product by emission intensities for the corresponding industries[6]: $\mathbf{e_j} = \mathbf{Ya_k}$. The next step then consists in determining, for each product, the share of output produced for domestic intermediate use ($\mathbf{s_j^{dy}}$). This is computed as $\mathbf{s_j^{dy}} = \mathbf{i_k}'\mathbf{Z^d}'(\hat{\mathbf{y}}_\mathbf{j})^{-1}$ where $\mathbf{y_j} = \mathbf{Yi_k}$ and $\mathbf{i_k}$ represents a (Kx1) vector of ones. Finally, total emissions for domestic intermediates are obtained by multiplying this share by emissions for each product: $e^d = \mathbf{s_j^{dy}}'\mathbf{e_j}$. This can be compared with total emissions for domestic production (e).

---

[6] Hence, it is implicitly assumed that, for each industry, emissions are distributed over all products in proportion to their share in output.

Graph 1 GHG, ACID and TOFP emissions for total domestic production and for domestic intermediates) in Belgian manufacturing (1995-2007, 1995=100)



Source: own calculations

The analysis in this paper is restricted to manufacturing industries and the manufactured goods produced by these industries. The manufacturing sector is defined as the 23 NACE Rev.1.1 2-digit industries 15-37. This industry detail is in line with that of the data used in input-output models on emissions embodied in trade (see overview in Table 1 in Wiedmann et al., 2007, p.22). As the product breakdown in the SUT is more detailed than the industry breakdown, 178 manufactured goods categories between CPA 15 and CPA 37 are taken into account. The decomposition is computed at the more detailed product breakdown. For the three composite indicators GHG, ACID and TOFP, emissions for domestic intermediates (e^d) account for respectively 19%, 17% and 20% of total emissions for domestic production (e) in Belgian manufacturing.[7] Graph 1 illustrates that for all three indicators both e and e^d decrease between 1995 and 2007. It stands out from the graph that, for all three indicators, e^d decreases at a faster pace than e over this period: 28% against 14% for GHG, 45% against 35% for ACID, and 42% against 33% for TOFP. The decomposition developed in the next chapter summarises user-related factors that have contributed to reducing emissions for domestic intermediates with a special focus on trade in intermediates.

---

[7] The rest is essentially made up of emissions for the production of goods for final consumption and exports.

4. Decomposition analysis

The starting point for the decomposition analysis is the level of emissions for domestic intermediates (e^d) for one particular period. Omitting time indices, the following expression can be written for e^d with economy-wide output (y) as a scaling factor:

$$e^d = ya^d \tag{1}$$

where a^d is the economy-wide emission-intensity for domestic intermediates. Changes between two periods (Δe^d)[8] can be analysed through a simple means-based decomposition of Δe^d based on expression (1). This reveals the relative importance of the overall scale of production and the overall emission intensity for domestic intermediates.[9]

$$\Delta e^d = \underbrace{\Delta a^d \bar{y}}_{intensity} + \underbrace{\bar{a}^d \Delta y}_{scale} \tag{2}$$

The *scale* effect measures the contribution of economy-wide output growth (Δy) to the change in emissions for domestic intermediates. Since output growth is in most cases positive, the scale effect is generally positive. The effect can be interpreted as follows: for a given production technology and fixed proportions of output for intermediate and final demand, an increase in overall output will raise output of intermediates and hence e^d. The *intensity* effect measures to what extent changes in the emission intensity a^d contribute to changing e^d. Given the fall in the overall emissions for domestic intermediates, the scale and intensity effects will be of opposite sign. Leaving the scale effect aside, the aim of the remainder of this chapter is to develop a decomposition of Δa^d that allows to get a grasp of user-related contributions to changes in this emission intensity. This is done in three steps.[10]

For the first step, using expressions from the previous chapter, write:

$$e^d = \mathbf{s}_{\mathbf{j}}^{\mathbf{dy}\prime}\mathbf{e}_{\mathbf{j}} = \mathbf{i}_{\mathbf{k}}{}'\mathbf{Z}^{\mathbf{d}\prime}\left(\hat{\mathbf{y}}_{\mathbf{j}}\right)^{-1}\mathbf{e}_{\mathbf{j}} \tag{3}$$

In order to develop a user-driven perspective, this expression can be rewritten as:

$$e^d = \mathbf{i}_{\mathbf{k}}{}'\mathbf{e}_{\mathbf{k}}^{\mathbf{d}} \tag{4}$$

---

[8] Time indices are omitted to avoid an excessively cumbersome notation. In the formulation of the decomposition below, the change in a variable between two periods, e.g. the first and the last year in the sample, is noted by Δ. The average of a variable between the same two periods is indicated by a bar.

[9] The decomposition here is one with two determinants (y and a^d) where the means of the expressions are used as weights. As explained in Dietzenbacher and Los (1998), the means-based expression for the decomposition is the most attractive one among the several equivalent exact decomposition expressions that exist and it allows to avoid interaction terms that are difficult to interpret. However, it only works in the case of two determinants.

[10] The stepwise approach presents the advantage of restricting the number of determinants to two in each step. Therefore, a means-based decomposition can be used in each step. The downside is that this sequencing matters for the weights in the overall decomposition expression.

where $\mathbf{e_k^d} = \mathbf{Z^{d\prime}a_j}$ represents emissions for domestic intermediates by purchasing industry. It is obtained by multiplying, for each product, intermediates of domestic origin ($\mathbf{Z^d}$) with emission intensities in the production of these products ($\mathbf{a_j} = \left(\mathbf{\hat{y}_j}\right)^{-1}\mathbf{e_j}$). Writing e^d as the sum of the elements of $\mathbf{e_k^d}$ as in (2) puts the emphasis on the demand side, i.e. on user-driven aspects of the emissions for domestic intermediates.

Expanding (4), the overall emission intensity for domestic intermediates can be expressed as:

$$a^d = \mathbf{s_k^{y\prime}a_k^d} \tag{5}$$

where $\mathbf{s_k^y} = y^{-1}\mathbf{y_k}$ stands for industry-shares in total output, and $\mathbf{a_k^d} = (\mathbf{\hat{y}_k})^{-1}e_k^d$ represents emission-intensities for domestic intermediates in the purchasing industries.[11] Expression (5) can then be used to decompose changes in a^d into a *between* effect and a within effect:

$$\Delta a^d = \underbrace{\Delta\mathbf{s_k^{y\prime}\bar{a}_k^d}}_{between} + \underbrace{\mathbf{\bar{s}_k^{y\prime}}\Delta\mathbf{a_k^d}}_{within} \tag{6}$$

The *between* effect measures the change in a^d that is due to a shift in the industry composition of output ($\Delta\mathbf{s_k^y}$). Emission intensities for domestic intermediates in the purchasing industries are maintained constant ($\mathbf{\bar{a}_k^d}$). The idea is that output of industries that use more emission intensive domestic intermediates may rise at a faster (slower) pace, leading to an increase (decrease) in the overall emission intensity for domestic intermediates. The *within* effect indicates the contribution of changes in emission intensities for domestic intermediates in purchasing industries ($\Delta\mathbf{a_k^d}$) to changes in a^d.

As a second step, $\Delta\mathbf{a_k^d}$ can be further decomposed. For this purpose, rewrite $\mathbf{a_k^d}$ using (3) and (4):

$$\mathbf{a_k^d} = \mathbf{s_{jk}^{dy\prime}a_j} \tag{7}$$

where $\mathbf{s_{jk}^{dy}}' = (\mathbf{\hat{y}_k})^{-1}\mathbf{Z^{d\prime}}$ is a matrix of product-level shares of domestic intermediates in the purchasing industry's output, i.e. domestic product use shares in total output. Using (7) to decompose $\Delta\mathbf{a_k^d}$ in the usual way:

$$\Delta\mathbf{a_k^d} = \underbrace{\Delta\mathbf{s_{jk}^{dy\prime}\bar{a}_j}}_{between} + \underbrace{\mathbf{\bar{s}_{jk}^{dy\prime}}\Delta\mathbf{a_j}}_{technique} \tag{8}$$

Here, the *technique* effect stands for use of cleaner technologies. It is determined by changes in the emission intensity in the production of the products that are used as intermediates ($\Delta\mathbf{a_j}$). The *between* effect measures the contribution of changes in the domestic product use share by industry ($\Delta\mathbf{s_{jk}^{dy}}'$).

---

[11] Hence, it is possible to write: $e^d = y\mathbf{s_k^{y\prime}a_k^d}$.

The third and last step consists in decomposing changes in the industry-level domestic product use shares. Therefore, given that $\mathbf{Z} = \mathbf{Z^d} + \mathbf{Z^m}$, i.e. total intermediates ($\mathbf{Z}$) are the sum of domestic intermediates ($\mathbf{Z^d}$) and imported intermediates ($\mathbf{Z^m}$) for each product and industry combination, the matrix of domestic product use shares can be rewritten as follows:

$$\mathbf{s_{jk}^{dy}}' = \mathbf{s_{kk}^{dz}} \mathbf{s_{kk}^{zy}} \mathbf{s_{jk}^{d}}' \tag{9}$$

where $\mathbf{s_{kk}^{dz}} = (\hat{\mathbf{z}}_\mathbf{k})^{-1} \hat{\mathbf{z}}_\mathbf{k}^\mathbf{d}$ with $\mathbf{z_k} = \mathbf{Z}'\mathbf{i_j}$ and $\mathbf{z_k^d} = \mathbf{Z^d}'\mathbf{i_j}$ is the diagonal matrix of industry-level shares of domestic in total intermediates, $\mathbf{s_{kk}^{zy}} = (\hat{\mathbf{y}}_\mathbf{k})^{-1} \hat{\mathbf{z}}_\mathbf{k}$ is the diagonal matrix of industry-level shares of total intermediates in output, and $\mathbf{s_{jk}^{d}} = \mathbf{Z^d} \left(\hat{\mathbf{z}}_\mathbf{k}^\mathbf{d} \right)^{-1}$ is a matrix of product shares in industry-level domestic intermediates. Define $\mathbf{r_{kj}} = \mathbf{s_{kk}^{zy}} \mathbf{s_{jk}^{d}}'$ such that:

$$\mathbf{s_{jk}^{dy}}' = \mathbf{s_{kk}^{dz}} \mathbf{r_{kj}} \tag{10}$$

The means-based decomposition for changes in $\mathbf{s_{jk}^{dy'}}$ is:

$$\Delta \mathbf{s_{jk}^{dy}}' = \bar{\mathbf{s}}_\mathbf{kk}^\mathbf{dz} \Delta \mathbf{r_{kj}} + \Delta \mathbf{s_{kk}^{dz}} \bar{\mathbf{r}}_\mathbf{kj} \tag{11}$$

For the purpose of highlighting the contribution of trade in intermediates to changes in domestic product use shares, note that $\Delta \mathbf{s_{kk}^{dz}} = -\Delta \mathbf{s_{kk}^{mz}}$ where $\mathbf{s_{kk}^{mz}}$ stands for the industry-level shares of imported in total intermediates. This corresponds to the industry-level offshoring intensity measure pioneered by Feenstra and Hanson (1996) and used in a large number of papers.[12] Introducing this into expression (11) makes it easier to interpret:

$$\Delta \mathbf{s_{jk}^{dy}}' = \underbrace{\bar{\mathbf{s}}_\mathbf{kk}^\mathbf{dz} \Delta \mathbf{r_{kj}}}_{efficiency} - \underbrace{\Delta \mathbf{s_{kk}^{mz}} \bar{\mathbf{r}}_\mathbf{kj}}_{offshoring} \tag{12}$$

The *efficiency* effect measures the contribution of changes in $\mathbf{r_{kj}}$ to $\Delta \mathbf{s_{jk}^{dy}}'$. Since $\mathbf{r_{kj}} = \mathbf{s_{kk}^{zy}} \mathbf{s_{jk}^{d}}'$, changes in $\mathbf{r_{kj}}$ depend on changes in the amount of intermediates used per unit of output ($\mathbf{s_{kk}^{zy}}$) and on changes in the product composition of domestic intermediates at the industry-level ($\mathbf{s_{jk}^{d}}'$). The offshoring effect reflects the contribution of replacing domestic by imported intermediates ($\Delta \mathbf{s_{kk}^{mz}}$). The negative sign indicates that more imports of intermediates lower the industry-level domestic product use shares.

Substituting first (12) into (8) and the result in turn into (6) yields the final expression for the decomposition of the change in the overall emission intensity for domestic intermediates.

$$\Delta a^d = \underbrace{\bar{\mathbf{s}}_\mathbf{k}^\mathbf{y}{}' \bar{\mathbf{s}}_\mathbf{jk}^\mathbf{dy}{}' \Delta \mathbf{a_j}}_{(a)} + \underbrace{\bar{\mathbf{s}}_\mathbf{k}^\mathbf{y}{}' \bar{\mathbf{s}}_\mathbf{kk}^\mathbf{dz} \Delta \mathbf{r_{kj}} \bar{\mathbf{a}}_\mathbf{j}}_{(b)} - \underbrace{\bar{\mathbf{s}}_\mathbf{k}^\mathbf{y}{}' \Delta \mathbf{s_{kk}^{mz}} \bar{\mathbf{r}}_\mathbf{kj} \bar{\mathbf{a}}_\mathbf{j}}_{(c)} + \underbrace{\Delta \mathbf{s_k^y}' \bar{\mathbf{a}}_\mathbf{k}^\mathbf{d}}_{(d)} \tag{13}$$

---

[12] Hijzen (2005) provides an overview of the use of the measure up to 2005. More recent examples of the use of this measure are Amiti and Wei (2009), Winkler (2010) or Michel and Rycx (2012).

The four terms in this overall decomposition can be interpreted as follows:

- *Technique* effect (a): this term measures the decrease/increase in a^d that is due to a decrease/increase in the emission intensity in the production of the products that are used as intermediate inputs, i.e. the effect of cleaner/dirtier production technologies.
- *Efficiency* effect (b): this term gives the contribution of the change in r_{kj} to the change in a^d. This effect will be negative/positive, i.e. contribute to the fall/rise in a^d, either if there is a fall/rise in the amount of intermediates used per unit of output or if the product composition of domestic intermediates shifts towards cleaner/dirtier products.
- *Offshoring* effect (c): this term indicates to what extent a rise/fall in the share of imported intermediates in total intermediates contributes to the fall/rise in a^d. This share is also frequently referred to as offshoring. Hence, the offshoring effect reflects the role played by the substitution of imported for domestic intermediates in lowering the overall emission intensity for domestic intermediates.
- *Industry composition* effect (d): this term measures the increase/decrease in a^d that can be attributed to a shift in the composition of output to industries that use more/less emission intensive domestic intermediates.

The first three terms (a)-(c) sum to the *within* effect in (6), and term (d) corresponds to the *between* effect in (6).

In the next chapter, results for the decomposition of emissions for domestic intermediates – expression (2) – and for the decomposition of the emission intensity for domestic intermediates – expression (13) – are reported using data from the AEA and SUT for Belgium.

5. Results

Decomposition results are reported for all three composite emission indicators (GHG, ACID, TOFP). As emphasized above, the focus is on the manufacturing sector and the goods it produces.[13] The period covered is 1995-2007. As a full dataset is available for each year, it becomes feasible to implement a dynamic decomposition procedure rather than a static one, i.e. to decompose changes year by year and to sum the results for each effect instead of simply decomposing the overall change between the first and the last period in the sample.[14]

Results for the decomposition in expression (2) – for Δe^d – are given in Table 1. Changes are expressed in tonnes (or thousands of tonnes) of emissions and not in percentage terms as in Graph 1. According to the findings for all three indicators, the overall fall in e^d is due to a reduction in the emission intensity, the *intensity* effect, which is negative and more than compensates the positive *scale* effect, i.e. the contribution of the increase in total output.[15]

Table 1 Decomposition of the change in emissions for domestic intermediates (Δe^d) in the manufacturing sector, 1995-2007, sum of year by year decomposition results

	GHG[1]	ACID[2]	TOFP[3]
1. Scale effect	2010.7	172.6	10254
2. Intensity effect	-4912.3	-653.4	-34601
3. Total change	-2901.5	-480.8	-24348

Source: own calculations

1: thousands of tonnes equivalent-CO_2; 2: tonnes equivalent-H+; 3: tonnes equivalent-NMVOC

The decomposition of the overall emissions intensity for domestic intermediates (Δa^d) provides further insights. Results of bringing expression (13) to the data for all three composite indicators are reported in Table 2. Changes are expressed in tonnes (or thousands of tonnes) of emissions per million euro of output.

For all three composite indicators, the reduction in the overall emission intensity for domestic intermediate demand (Δa^d) is driven by the negative *within* effect, which more than compensates the positive but small *between* effect. The result for the *between* effect implies that there has been a slight shift in the composition of output to manufacturing industries that, on average, use more emission intensive domestic intermediates. However, the contribution of this shift to the overall change is almost negligible. The three rows at the bottom of Table 2 illustrate the split of the dominant *within* effect into its three parts – the *technique* effect, the *efficiency* effect and the *offshoring* effect – according to expression (13). The shares of these effects in the total *within* effect are also reported. Given the very small size of the between effect, this is basically equivalent to contributions to the total change in a^d.

---

[13] NACE Rev.1.1 2-digit industries 15-37 and corresponding CPA product categories.

[14] However, in the present case, the differences in the results between the dynamic and the static decomposition prove to be minor. Nonetheless, the dynamic procedure has the advantage of revealing trends in the effects over time.

[15] The sign of the scale effect is determined by the sign of the change in economy-wide output (Δy). This is the same for all three composite emission indicators. Therefore, since there is positive output growth between 1995 and 2007, the scale effect is positive for all three indicators as shown in Table 1.

Table 2 **Decomposition of the change in the emission intensity for domestic intermediates (Δa^d) in the manufacturing sector, 1995-2007, sum of year by year decomposition results**

	GHG[1]	ACID[2]	TOFP[3]
Total Change	-0.0284	-0.0038	-0.1995
Between effect (d)	0.0017	0.0001	0.0074
Within effect (a)+(b)+(c)	-0.0301	-0.0039	-0.2069
of which			
(a) Technique effect	-0.0212 (70%)	-0.0029 (75%)	-0.1551 (75%)
(b) Efficiency effect	-0.0012 (4%)	-0.0002 (5%)	-0.0112 (5%)
(c) Offshoring effect	-0.0077(26%)	-0.0008 (20%)	-0.0406 (20%)

Source: own calculations

Values in brackets are percentage shares of the within effect.

1: thousands of tonnes equivalent-CO_2 / millions of euros; 2: tonnes equivalent-H+ / millions of euros; 3: tonnes equivalent-NMVOC / millions of euros

The *technique* effect largely dominates. For each of the emission indicators, the decomposition attributes 70% or more of the reduction in a^d to this effect. This means that the reduction in the overall emission intensity for domestic intermediates is mainly due to a lower emission intensity in their production, i.e. the use of cleaner production techniques. The substitution of domestic intermediates by imported intermediates also contributes to reducing the overall emission intensity for domestic intermediates. This is the *offshoring* effect, which represents 20-25% of the fall in a^d. As documented in Hertveldt and Michel (2012), the share of imported intermediates in total intermediates is on the rise, which, according to (13) leads to a negative *offshoring* effect. Finally, the remaining reduction in a^d is due to efficiency gains. These are gains in terms of the use of intermediates per unit of output or in terms of a shift in the domestic intermediate input composition in favour of less emission intensive products.[16] However, the contribution of these efficiency gains is only minor. As illustrated in Table 3, the *efficiency* effect represents about 5% of the reduction in the overall emission intensity for domestic intermediates.

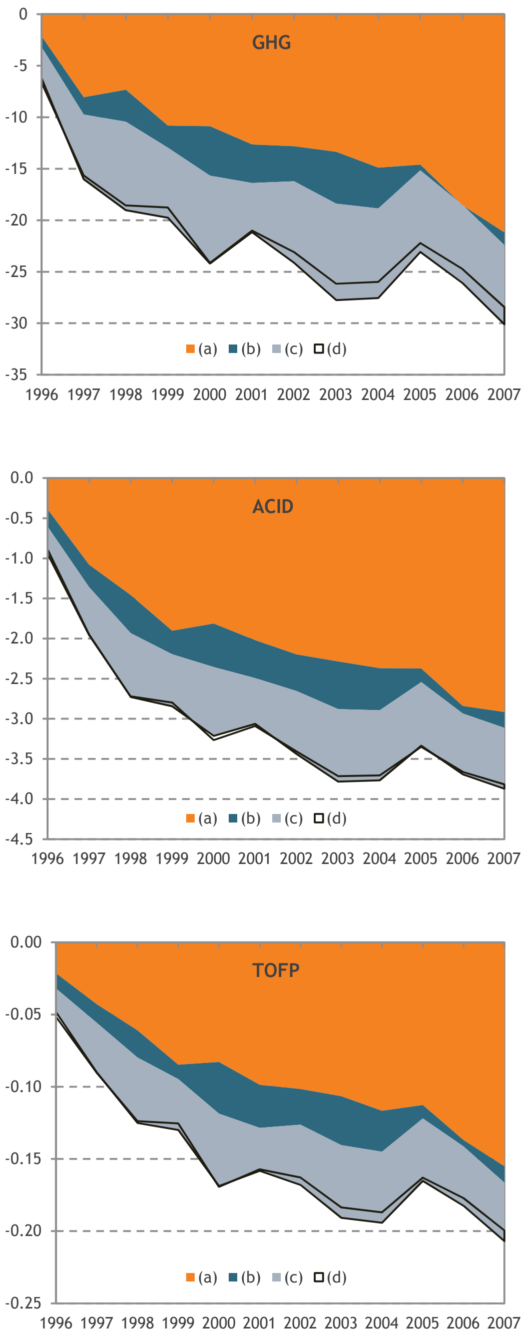
The dynamic decomposition procedure allows for a graphical representation of the decomposition of Δa^d over time. This is shown in Graph 2 for each composite emission indicator. The *technique*, *efficiency*, *offshoring* and *between* effects are cumulated in absolute value over the period 1995-2007.[17]

---

[16] A further decomposition of this effect shows that it is driven by gains in the use of intermediates per unit of output.

[17] The final decomposition result as reported in Table 3 can be read from the graph by taking the values for 2007. However, note that in Graph 3, there is a change in units compared to Table 3 for GHG and ACID.

Graph 2 **Year by year trends in the decomposition of the change in the emission intensity for domestic intermediates (Δa^d) in the manufacturing sector, 1995-2007, cumulative results**



Source: own calculations
1: tonnes equivalent-CO_2 / millions of euros;
2: tonnes equivalent-H+ / thousands of euros;
3: tonnes equivalent-NMVOC / millions of euros
(a) technique effect, (b) efficiency effect, (c) offshoring effect, (d) between effect

Note: Since it is mostly positive, the between effect has no fill colour to avoid overlap with the offshoring effect. When the cumulative between effect is positive/negative, the inner/outer black line indicates the overall change in a^d.

The results for the three composite emission indicators are also similar over time. Most of the reduction in the overall emission intensity for domestic intermediates (Δa^d) occurs between 1995 and 2000. During this period, the reduction is driven by the *technique* effect and the *offshoring* effect, and, to a lesser extent, also by the *efficiency* effect. Over the years 2000-2007, there is still a fall in a^d, but the pace of the reduction is much slower than during the years 1995-2000. The reduction during the period 2000-2007 is entirely due to technological change, i.e. a lower emission intensity in the production of the goods used as intermediates. Offshoring no longer contributes to lowering a^d and the *efficiency* effect even becomes positive.

Finally, the share of the reduction in emissions for domestic intermediates that is due to the substitution of imported for domestic intermediates can be calculated for all three composite emission indicators. This is the contribution of offshoring to Δe^d. The calculation combines decomposition results from Tables 2 and 3. According to results in Table 3 for GHG (ACID/TOFP), the *offshoring* effect represents 26% (20%/20%) of the *within* effect, which in turn represents 106% (103%/104%) of the total change in the emission intensity for domestic intermediates (Δa^d). Hence the contribution of offshoring to Δa^d amounts to 27% (20%/20%).

6. Conclusion

As production processes become ever more fragmented internationally, domestic intermediates are replaced by imported intermediates and the share of imported in total intermediates, i.e. offshoring, rises. One of the consequences of this is that less air pollution is emitted for the production of intermediates leading to a reduction in total manufacturing emissions in the home country. The main purpose of the decomposition analysis developed in this paper was to get a rough idea whether and to what extent the substitution of imported for domestic intermediates contributes to lowering domestic emissions of air pollutants. The results show that, over the period 1995-2007, offshoring did make a positive contribution to the fall in the emission intensities for domestic intermediates in the Belgian manufacturing sector for three aggregate air emission indicators. This contribution amounted 27% of the fall in the intensity of greenhouse gas emissions, 20% of the fall in the intensity of acidifying emissions and 20% of the fall in the intensity of tropospheric precursor emissions in Belgian manufacturing between 1995 and 2007.

The analysis in this paper highlights the specific role played by trade in intermediates in avoiding emissions of air pollutants in the home country. The decomposition that has been developed constitutes the first attempt to measure the size of the contribution of offshoring to the fall in emission intensities. However, this does not imply a reduction in emissions at a global scale: the emissions have simply been displaced as the intermediates are now produced abroad. Depending on the foreign technology, the level of emissions may be higher than before offshoring. Moreover, as pointed out in Cadarso et al. (2010), the international fragmentation of production and offshoring increase the distance travelled by goods before reaching the final consumer, thereby giving rise to extra air pollution emitted due to transportation. Hence, offshoring may increase emissions at a global scale even if foreign production of intermediates is cleaner.

Two issues in particular should be addressed in future research. On the one hand, the decomposition should be applied to data from other countries in order to test the results obtained for Belgium. In a multi-country setting, the overall impact of offshoring on emission levels may be assessed taking into account foreign technology and emissions for extra transportation. On the other hand, the finding that offshoring, whatever its underlying cause, contributes to lowering air emissions raises the question of whether firms engage into offshoring to avoid air emissions. Further research is needed to investigate whether this causality can be established.

References

Ahmad, N. and A. Wyckoff (2003), "*Carbon Dioxide Emissions Embodied in International Trade of Goods*", OECD Science, Technology and Industry Working Papers, 2003/15, OECD Publishing, Paris

Amiti, M. and Wei, S. (2009), "*Service offshoring and productivity: evidence from the US*", The World Economy, February 2009, vol. 32, pp. 203-220

Antweiler, W., Copeland, B. and M. Taylor (2001), "*Is Free Trade Good for the Environment?*", American Economic Review 91, pp.877-908

Avonds, L., G. Bryon, C. Hambÿe, B. Hertveldt, B. Michel and B. Van den Cruyce (2012), "*Supply and Use Tables and Input-Output Tables for Belgium 1995-2007: Methodology of Compilation*", Federal Planning Bureau, Working Paper 6-12, Brussels

Cadarso, M.-A., Lopez, L.-A., Gomez, N. and M.-A. Tobarra (2010), "*CO_2 emissions of international freight transport and offshoring: Measurement and allocation*", Ecological Economics 69, pp.1682-1694

De Backer, K. and N. Yamano (2012), "*International Comparative Evidence on Global Value Chains*", OECD Science, Technology and Industry Working Papers, 2012/03, OECD Publishing, Paris

Dietzenbacher, E. and B. Los (1998), "*Structural Decomposition Techniques: Sense and Sensitivity*", Economic Systems Research 10, pp.307-324

Eurostat (2009), "*Manual for Air Emission Accounts*", Eurostat Methodologies & Working Papers, Luxemburg

Feenstra, R. and Hanson, G. (1996), "*Globalisation, Outsourcing, and Wage Inequality*", American Economic Review, vol. 86, pp.240-245

Grether, J.-M., Matthys, N. and J. de Melo (2010), "*Global manufacturing SO2 emissions: does trade matter?*", Review of World Economics 145, pp.713-729

Grossman, G. and A. Krueger (1991), "*Environmental Impacts of a North American Free Trade Agreement*", NBER Working Paper n°3914

Hertveldt, B. and B. Michel (2012), "*Offshoring and the Skill Structure of Labour Demand in Belgium*", Federal Planning Bureau, Working Paper 7-12, Brussels

Hijzen, A. (2005), "*A bird's eye view of international outsourcing: data, measurement and labour demand*", Economie Internationale 104, pp.45-63

Hummels, D., Ishii, J. and K.-M. Yi (2001), "*The nature and growth of vertical specialisation in world trade*", Journal of International Economics 54, pp.75-96

Janssen, L. and G. Vandille (2011), "*Air Emission Accounts for Belgium (1990-2007)*", Report for Eurostat, Federal Planning Bureau, January 2011, Brussels

Johnson, R. and G. Noguera (2012), "*Fragmentation and Trade in Value-Added over Four Decades*", NBER Working Paper n°18186

Levinson, A. (2009), "*Technology, International Trade, and Pollution from US Manufacturing*", American Economic Review 99, pp.2177-2192

Michel, B. and Rycx, F. (2012), "*Does offshoring of materials and business services affect employment? Evidence for a small open economy*", Applied Economics, vol. 44, pp.229-251

Nakano, S., Okamura, A., Sakurai, N., Suzuki, M., Tojo, Y. and N. Yamano (2009), "*The Measurement of CO_2 Embodiments in International Trade: Evidence from the Harmonised Input-Output and Bilateral Trade Database*", OECD Science, Technology and Industry Working Papers, 2009/3, OECD Publishing, Paris

Peters, G. (2008), "*From Production-based to Consumption-based National Emission Inventories*", Ecological Economics 65, pp.13-23

Peters, G. and E. Hertwich (2008), "*CO_2 Embodied in International Trade with Implications for Global Climate Policy*", Environmental Science & Technology 42, pp.1401-1407

Serrano, M. and E. Dietzenbacher (2010), "*Responsibility and trade emission balances: An evaluation of approaches*", Ecological Economics 69, pp.2224-2232

Van den Cruyce, B. (2004), "*Use Tables for Imported Goods and Valuation Matrices for Trade Margins - an Integrated Approach for the Compilation of the Belgian 1995 Input-Output Tables*", Economic Systems Research 16, pp.33-61

Wiedmann, T., Lenzen, M., Turner, K. and J. Barrett (2007), "*Examining the Global Environmental Impact of Regional Consumption Activities – Part 2: Review of Input–Output Models for the Assessment of Environmental Impacts Embodied in Trade*", Ecological Economics 61, pp.15-26

Wiedmann, T., Wood, R., Minx, J., Lenzen, M., Guan, D. and R. Harris (2010), "*A Carbon Footprint Time Series of the UK – Results from a Multi-Region Input-Output Model*", Economic Systems Research 22, pp.19-42

Winkler, D. (2010), "*Services Offshoring and its Impact on Productivity and Employment: Evidence from Germany, 1995-2006*", The World Economy, December 2010, vol. 33 (12), pp.1672-1701

Yeats, A. (2001), "*Just How Big is Global Production Sharing?*" in Arndt, S., and Kierzkowski, H., Fragmentation: New Production Patterns in the World Economy, Oxford University Press.

Appendix

Table A1 – Types of air emissions in the Belgian AEA

Name	Symbol	Unit (evaluation)
Methane	CH_4	Tonnes
Nitrous oxide	N_2O	Tonnes
Nitrogen oxides	NO_x	Tonnes (NO_2 equivalent)
Carbon monoxide	CO	Tonnes
Carbon dioxide	CO_2	Thousands of tonnes
Sulphur oxydes	SO_x	Tonnes (SO_2 equivalent)
Ammonia	NH_3	Tonnes
Non-Methane Volatile Organic Compounds	NMVOC	Tonnes
Particulate matter	$PM_{2.5}$ and PM_{10}	Tonnes (mass equivalent of filter measurements)
Hydrofluorocarbons	HFC	Tonnes (CO_2 equivalent)
Perfluorocarbons	PFCs	Tonnes (CO_2 equivalent)
Sulphur hexafluoride	SF_6	Tonnes (CO_2 equivalent)
Chlorofluorocarbons	CFC	Tonnes (CO_2 equivalent)
Hydrochlorofluorocarbons	HCFC	Tonnes (CO_2 equivalent)

Source: Eurostat (2009) and Janssen and Vandille (2011)